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Study Element Report

HAWAII WATER RESOURCES REGIONAL STUDY

Honolulu, Hawaii

WATER AND RELATED LAND RESOURCES ALLOCATION MODEL

Supplement to
PLAN FORMULATION
Study Element Report

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The economy of a region needs to grow in order:

a. to meet the increased demand for more goods and services generated by a growing population, and

b. to create enough jobs for the increased population as well as for those who will be released from industries because of a continued increase in labor productivity.

The growth of a region, however, is restrained by the quantity and the quality of the natural resources in the region. Generally, man can modify the existing natural resources by either developing more supply or by improving availability of existing supplies. Measures of this nature require investment and lead time for implementation. Therefore, it is important to predict the needs and to inventory the resources many years in advance so the needed economic growth will not be impeded by lack of proper resources.

How to best modify nature requires a plan.

A plan may be defined as a collection of actions proposed to remove limiting factors (primarily resource shortage, unreasonable demand, etc.) which prevent either partially or completely the achievement of specific goals (needs) established for a county, a region, a state, or a nation. The set of actions which accomplishes the task best (consistent with the adopted criteria) is the optimal plan. The tasks involved to derive such a plan primarily consist of:

1. Identifying resource shortages.

2. Speculating which actions are most likely to succeed in removing the shortages.
3. Evaluating their feasibility, their benefits, and their costs.

How to efficiently accomplish these tasks remains a difficult problem.

PAST PLANNING EXPERIENCE AND NEED OF NEW APPROACH

Past adverse experience in growth lead to the recent emphasis on environmental and social needs, which forbid considering the economic growth alone. The need for a better environment and social conditions behooves us to consider all needs together:

1. economic,
2. environmental, and
3. social.

The added dimensions made the already complex planning task even more so. The creation of a conceptual framework (model) for orderly evaluation of alternative plans to fulfill our needs now becomes a necessity.

The current trend of planning also encourages citizen participation. Their input must be evaluated and reasonable ones should be met. The citizen should also be informed whether or not his needs can be met and the reason for it. Also, what economic sacrifice they must make to achieve some of their social or environmental goals, or vice versa. In other words, a planning group or the professional planners should be able to provide a measurable impact and means associated with the achievement of the needs outlined by a citizen group. It is conceivable that needs may be modified when their true impact is demonstrated. When factors exogenous to the region change, needs may also change. In short, the planning process may become a continuous effort.

Many government agencies are engaged in planning under their separate jurisdictions, but because of the inseparable nature of the resource planning problem,often the planning activity of one agency destroys the plan adopted by another. Waste of this nature is common. A centralized planning approach which has been tried in many places usually has not successfully eliminated the pet planning projects of individual agencies. Centralization must also stop at a certain level under a democratic government in which separation of power must be maintained. Therefore, successful planning must actively solicit inputs from many diverse groups of citizens as well as government agencies to guarantee final acceptance and implementation.

In order to have such a large group of people working effectively together, a common tool to measure the merit of a proposal is needed. The tool must be able to display impacts in all phases of concern in a short period of time. Speed is essential so that most of the ideas or propositions any group cares to offer can be considered.

In this environment, no one dominates and the planning staff plays the role of a moderator. Decision makers contribute also. No one will be neglected. In fact, it becomes a true cooperative process. This is necessary because no one person can define what is the best in terms of environment, economy, or society. Expertise of many disciplines is needed. An economical and fast method to accomplish this is almost indispensible if good planning results and meaningful citizen participation are to be guaranteed. The model must be so programmed that its input labor can be minimized to reduce overall analysis time. Effort to make the model comprehensible to more people is also very desirable.

NEEDS AND RESOURCES

Needs, as a rule, always generate demand for resources. Usually those resources available where and when needed meet the demand. The spatial and timely distribution of resource demands and supplies are important to determine whether there is adequate resource to meet the demand generated by the various needs.

If needed resources are not available either in terms of quantity, location, or time, then needs can not be completely fulfilled. In other words, resources can become a limiting factor preventing us from achieving what we want. Possible actions for removing resource as a limiting factor are:

1. Improving resource availability by transferring resources such as water spatially and timely. Building water distribution networks or reservoirs are examples of this type.
2. Increasing resource quantity by recycling, using low-grade sources or tapping new resources.
3. Develop new technology which leads to reduced demand for resources per unit of production.
4. Reducing our economic need and/or distributing industry to locations where resources are ample.

Similarly, when recreation facilities, housing densities, and open space become limiting resources, one can

1. zone more urban land, and park land, at the expense of other land uses;
2. reduce the quality of life standard by decreasing per capita needs or allowance of such resources; and
3. reduce economic growth and/or optimize the distribution of economic activities.

These actions modify either resource supply or demand to meet a specific set of needs. In fact, the set of actions developed to achieve the specific needs constitutes a plan. Whether a plan is feasible primarily depends on whether the resource supply can indeed meet the demand generated by the needs. Therefore, a model is nothing more than a set of relationships which check if resource supply is adequate plus one additional relationship which forces the optimal distribution of economic activities. Relationships describing the interdependence of the various economic activities of the economy must also be incorporated into the model. These relationships are listed in the appendix. Together, they constitute the model which will be used to assist the planners in arriving at an acceptable plan.

RESOURCE PLANNING AND THE MODEL

A regional plan is a collection of proposed actions designed to remove or overcome limiting factors for the purpose of achieving economic, social, and environmental goals or needs of the people in the region. There are infinitely many feasible plans. The best plan is the one which brings the maximum benefit to the most people at the lowest cost, while environmental and social impacts are acceptable.

The benefit brought about by an action of social significance should be displayed in the social account. Similarly, an environmental account should display benefits resulting from implementation of actions classified environmental. Actions with emphasis on removing production limitation alone generates economic benefit. Environmental as well as social action with negative results are often introduced to induce economic gains which are considered more important.

The model* consists of a set of relations which avoids selecting as the solution an economy or a set of economic activities which together demand more resources than are available in the region. The optimization relation (the objective function) of the model attempts to generate as much service and product as possible to approximate the projected need (for given resources) by distributing economic activities to areas with ample resources to support them. Detailed discussion on how to use the model for planning is illustrated in the example.

* See Appendix VI, Display of the Model Structure.

In principle, planning should be an iterative process. Needs generated by a projected future population are first identified. Problems such as resource shortage must be detected and tentative remedies developed. Finally, the feasibility and the economics of the developed actions must be evaluated. This procedure may repeat itself many times before a final plan is deemed acceptable. The explicit definition of regional needs in the model reduces ambiguity when planners must identify the needs or goals. The model distributes economic activities to where resources are abundant so that the identified goals can be met. If resources are in shortage, the exact type, location, time, and quantity will be detected and printed by the model. The economic impact of such a shortage is also available. The model supplies the information which helps planners to identify possible measures to overcome the shortage. Simultaneously, the model also indicates the benefit of these measures quantatively. These benefits are input information for calculating the accounts required by the principles and standards for water resource planning. The flowchart in Figure 1 describes the iterative planning procedure with emphasis showing the role played by the model.

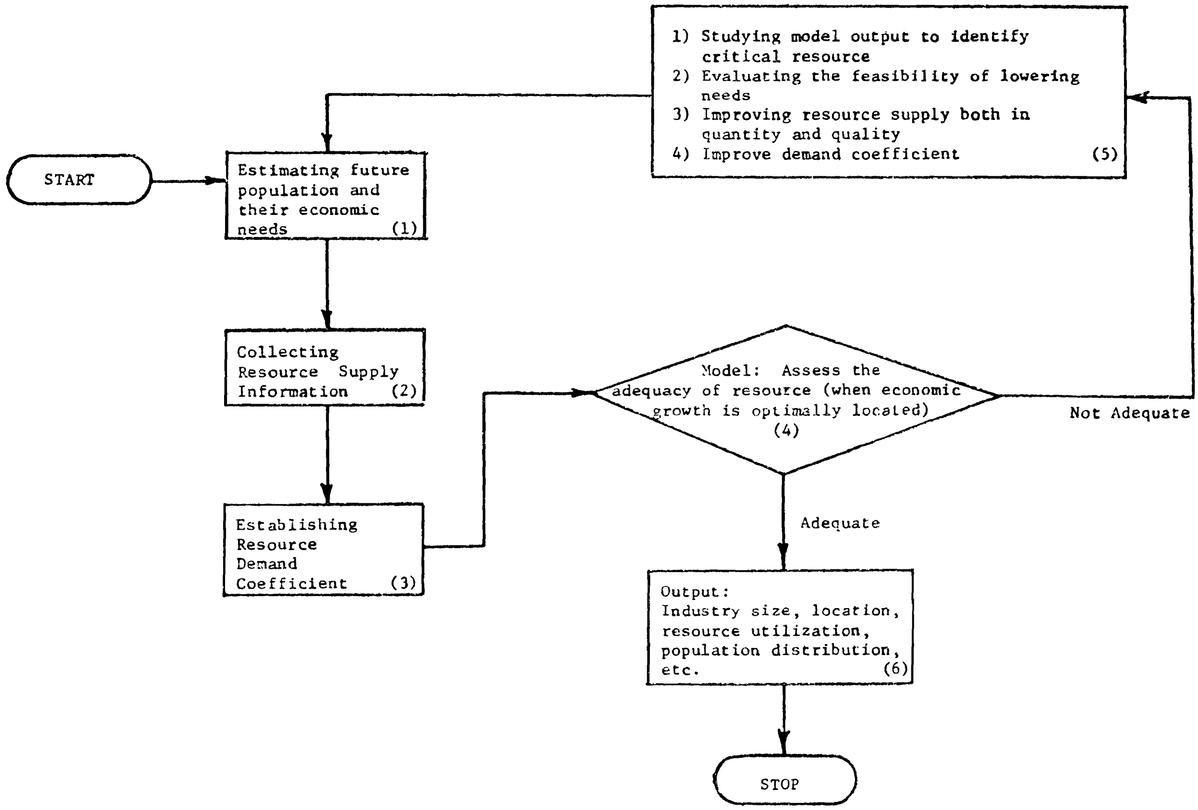


Figure 1. Water Resource Planning Process and the Model

MATRIX GENERATOR AND THE PLANNING PROCESS

As shown in Figure 1, planning is an iterative process. Adjustment of inputs and converting the adjusted inputs into the model matrix for analysis is repeated many times before a final plan is developed. For an n region, m resources plus water, ℓ industries, j population dependent industries per region, k population integrated areas, a population constraint per region and an overall population constraint for the entire area, a model of

$$\ell + n \times m + n \times 12 + n \times j + n \times 1 + 1 + k \text{ constraints (or rows)}$$

and

$n \times \ell$ structural variables needs to be generated. For n = 5, m = 10, ℓ = 54, j = 0, and k = 3, a 174 (objective function included) rows and 449 structural variables model is generated. A matrix with 9926 non-zero elements (logical variables not included) must be constructed from the input data. The task of even constructing once this matrix on cards amounted to thousands of calculations, table preparation, and finally the punching of the approximately 5000 cards. A means to reduce this chore must be developed. A matrix generator, which is essentially a computer program for converting input data in a more basic form into the model matrix, will provide a very handy tool which makes the planning process much more efficient.

The matrix generator will input a minimum amount of data sufficient to derive the coefficients needed in model relations (see Appendix I eq. 1 to 9). The input data to the matrix generator are described in Appendix II.

KAUAI COUNTY AS AN EXAMPLE

Kauai (see Figure 2) is the smallest of the four counties in the state of Hawaii. Hydrologically it is divided into five areas as shown.

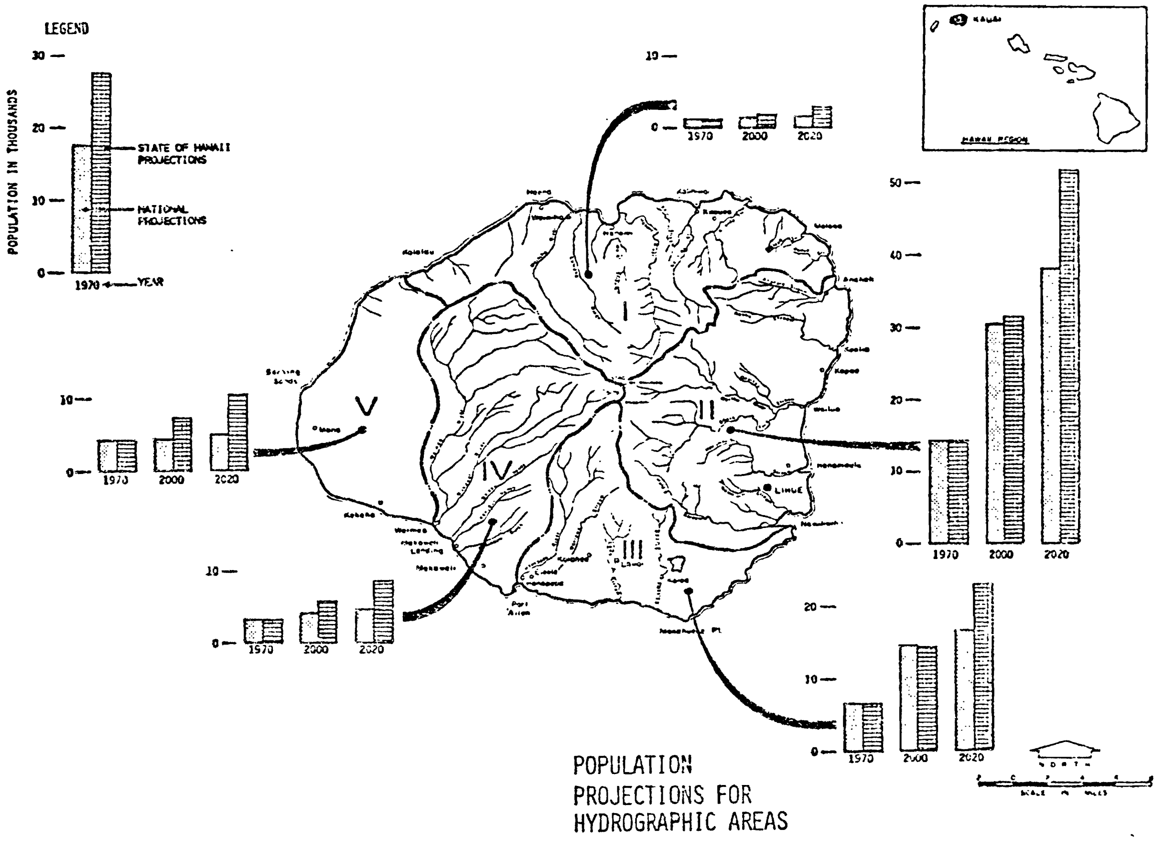


Figure 2. Island of Kauai, Showing Population Projections

Their condition in the year of 1970 is shown in Tables 1through 4 (see Appendix V for input data). In anticipation of a growing population and increased productivity, its economy needs (estimated by DPED) to grow to approximately 746.57 million dollars (1970 dollar) in the year 2000. Its agriculture and visitor industries are expected to grow to 84.03 and 237.66 million dollars respectively.

Table 1. Quality of life

Hydrographic area	Urban density in person/acre	Beach park density in person/acre	Overall density in person/acre
1	0.367	38.922	0.012
2	3.980	231.857	0.169
3	2.373	970.874	0.136
4	19.002	515.809	0.042
5	4.802	101.189	0.084

Table 2. Economy

Hydrographic area	Total Industry output in 10^6\$	Visitor industry output in 10^6\$	Agriculture output in 10^6\$
1	6.41	4.08	0.81
2	80.85	7.66	23.35
3	36.59	4.14	13.42
4	24.78	7.69	21.01
5	22.36	1.01	13.17
Totals	170.99	24.58	71.76

Table 3. Water quality *

Hydrographic area	Solids in water lb/10^6 gallon	BOD in water lb/10^6 gallon	Nitrogen in water lb/10^6 gallon	Phosphorus in water lb/10^6 gallon
1	118.0	1.294	0.715	0.065
2	483.6	2.601	1.439	0.130
3	665.5	3.765	2.078	0.187
4	440.7	3.322	1.863	0.168
5	2505.2	13.297	7.426	0.669

* Area pollutants generated/total runoff

Table 4. Social indicators

Hydrographic area	Residence population in persons	Employment in persons	Net Commuting out of area to work in persons
1	1,182	532	0
2	14,159	6,371	0
3	6,850	3,082	0
4	3,173	1,428	0
5	4,159	1,872	0

As discussed previously, the merit of a plan must be judged with respect to a person or a group of persons. Since the clientele was not clearly defined, the plans to be presented here are only an exercise for the purpose of showing what kind of end product one can expect from this kind of planning and also how the model was used to develop the plan.

Display of Final Plan

Two plans for meeting the projected year 2000 needs and population growth were obtained. The measures of each plan and their merits are displayed in Tables 5 and 6. The final economic and environmental condition of Kauai after Plan 1 is implemented are displayed in Figures 4 to 7. They are displayed together with the 1970 condition to show how much change one can expect if Plan 1 is adopted.

How Plans Were Obtained

Measures of the displayed plans tabulated in Tables 5 and 6 are responses to resource deficiencies indicated (see Figures 3-a and 3-b for water and land shortage) in the output of each application of the model. Planning either with or without a model is an iterative process of developing measures to overcome bottlenecks which may prevent the achievement of projected needs. However, a planning process without the assistance of a model would have to depend on intuition and past experience of planners to pinpoint the deficiency. Tedious calculations for evaluating any proposal must also follow. For multi-objective planning, the intuitive approach to the identification of problems may not be very effective. Calculations involved in evaluating any proposal selected for removing

Table 5. Summary of Plan 1

Action No.	Description of Measure	Change in GRP, 10^6\$	Value of Measure, in 10^6\$				
			National Economy	Regional Economy	E.Q.		Social
					Water Quality	Quality of Life	
0	1970 base year	0.0					
1	a) The growth of economy is guided to where resources are abundant. Growth in each area follows strictly past growth pattern b) Water quality and quality of life maintained at 1970 level	170.15	102.19	67.96			
2	a) Water quality allowed to deteriorate to one-half of the 1970 standard if necessary b) Quality of life indicators may have the same deterioration	190.50	114.41	76.09	-190.50		
3	Transfer 26 million gallons water per day during April to October from area 2 to 3	37.22	22.35	14.87			
4	a) Zoning 20 acres flood hazard land into urban in area 2 b) Similarly zoning 8 acres of flood hazard land into urban in area 3 ? c) Increase slightly area 2 overall density (about 1.28 percent)	0.47	0.28	0.19			-0.47
5	Let economy grow freely in areas 1, 4 and 5 to a population ceiling of 2370, 6350 and 7900 respectively	5.94	3.57	1.99			
6	Let economy in areas 1, 4 and 5 to have more growth freedom by lifting their year 2000 population to 3000, 7000 and 8270	1.42	0.85	0.57			

Table 6. Summary of Plan 2

No.	Description of Measure	Change in GRP, 10^6\$	Value of Measure, in 10^6\$				
			National Economy	Regional Economy	E.Q.		Social
					Water Quality	Quality of Life	
0	1970 base year	0.0					
1	a) The growth of economy is guided to where resources are abundant. Growth in each area follows strictly past growth pattern b) Water quality and quality of life maintained at 1970 level	170.15	102.19	67.96			
2	a) Water quality allowed to deteriorate to one-half of the 1970 standard if necessary b) Quality of life indicators may have the same deterioration	190.50	114.41	76.09		-190.50	
3	Let economy in each hydrographic area grow freely without following past pattern	9.25	5.55	3.70		-9.25	
4	a) Water quality allowed to deteriorate 2.39% of the standard after measure 2 b) Quality of life deteriorates a similar amount	5.83	3.50	2.33		-5.83	
5	a) Water quality deteriorates to 3.716% of the standard after measure 2 b) Quality of life deteriorates a similar amount	8.76	5.26	3.50		-8.76	

an anticipated difficulty may also become an insurmountable task. The model was developed to overcome some of these difficulties. The model not only provides a systematic way of identifying trouble but also suggests the impact of a proposed solution. The steps followed in arriving at Plan 1 will be retraced for the purpose of demonstrating the use of the model.

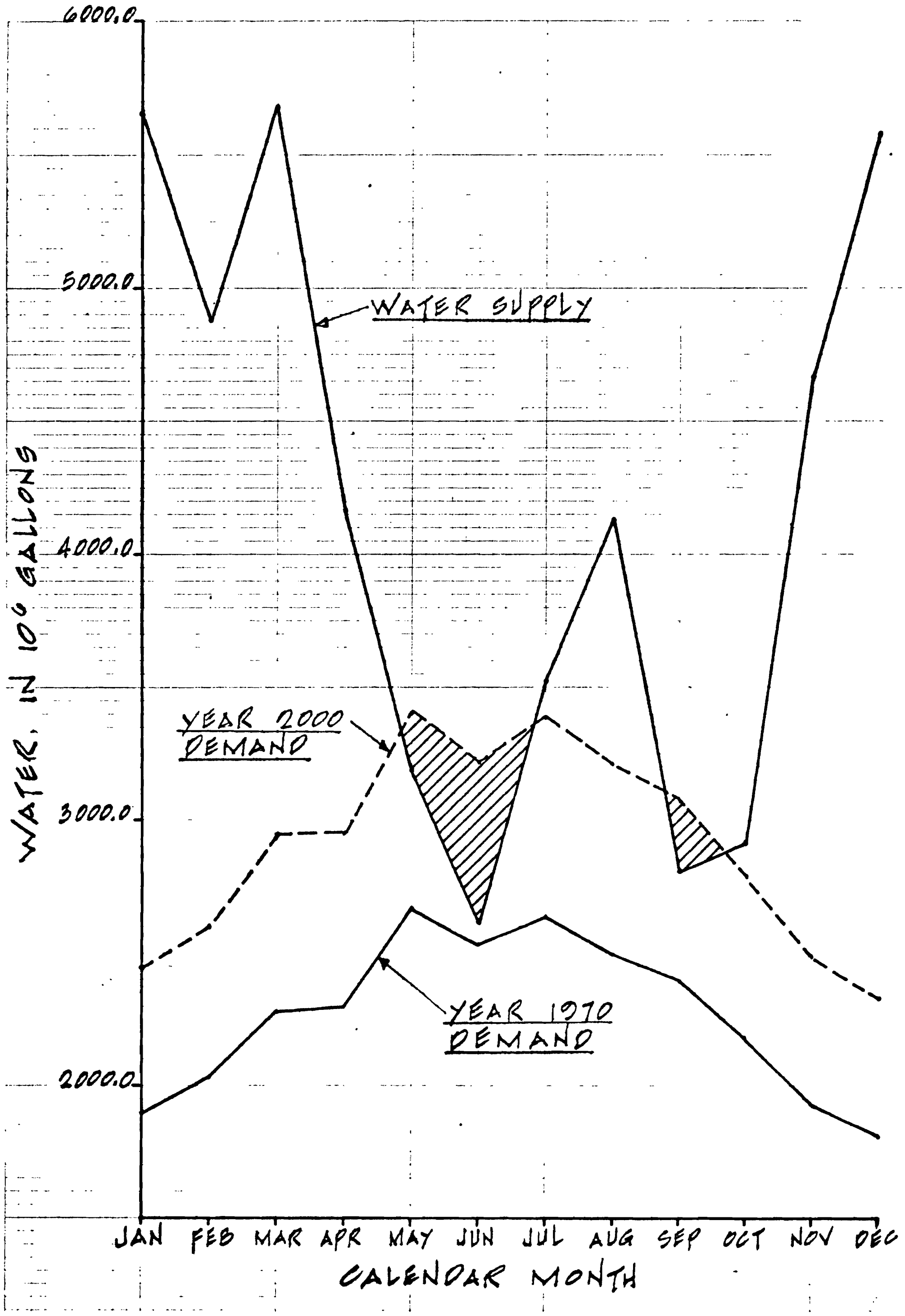


Figure 3-a. Expected Year 2000 Water Shortage in Hydrographic Area III

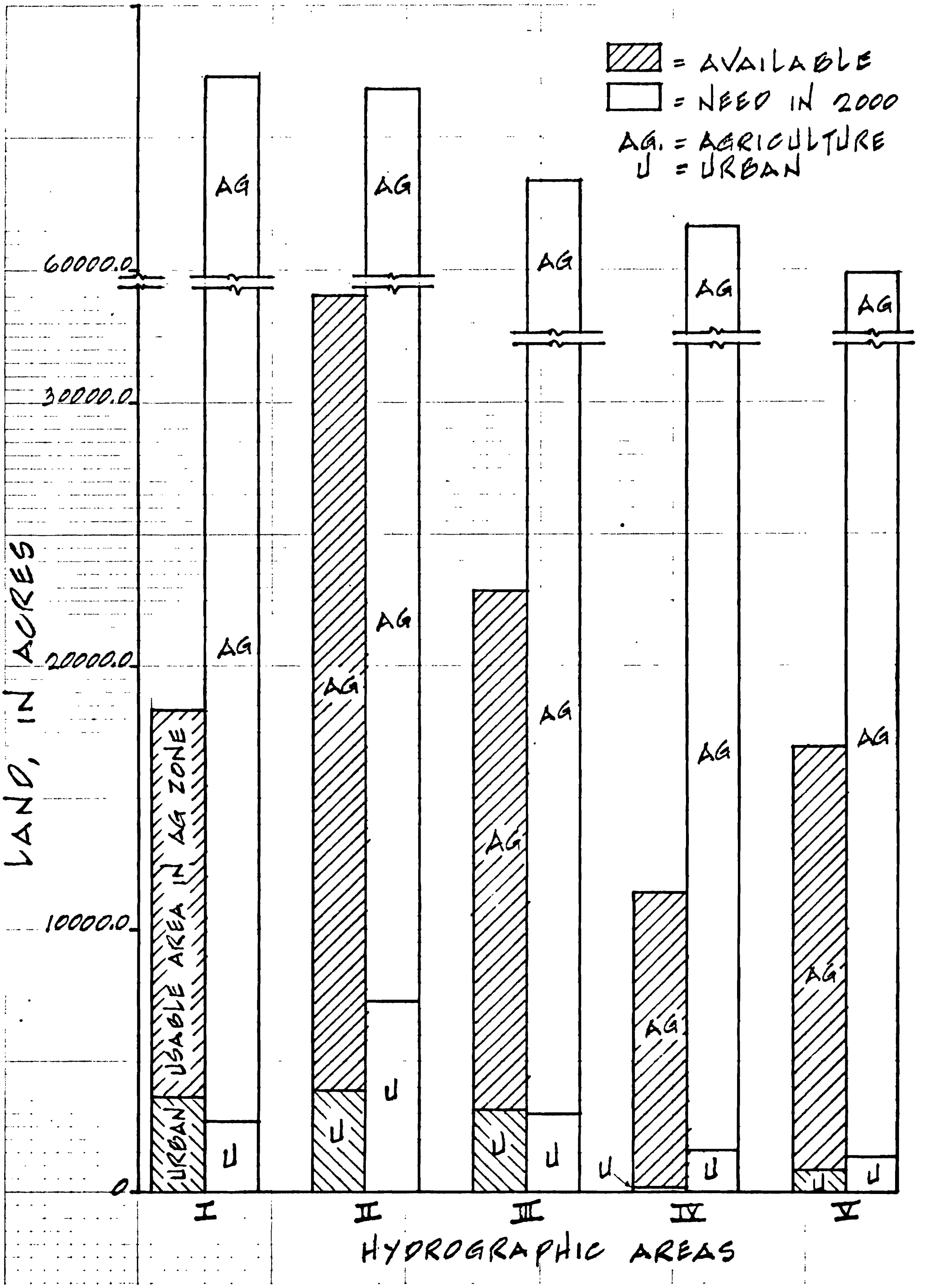


Figure 3-b. Available Agriculture and Urban Land Versus Need in Year 2000

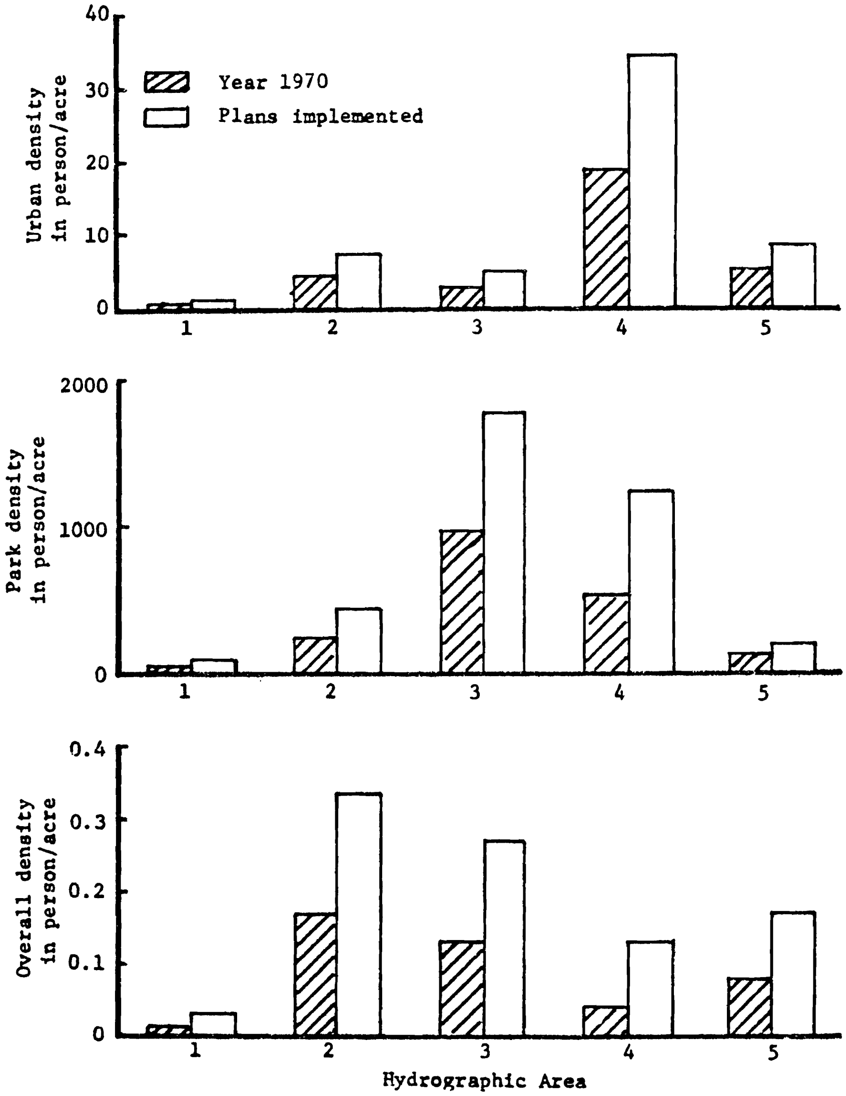


Figure 4. Quality of Life Indicators

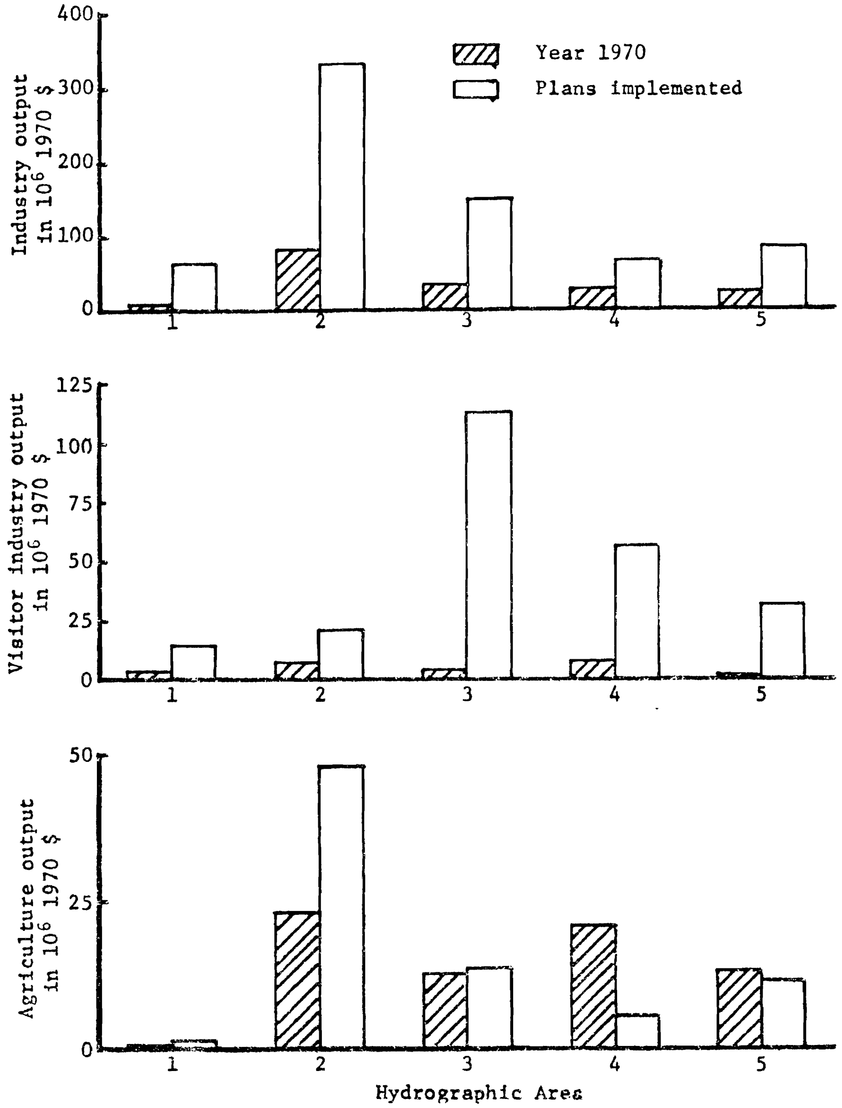


Figure 5. Economy

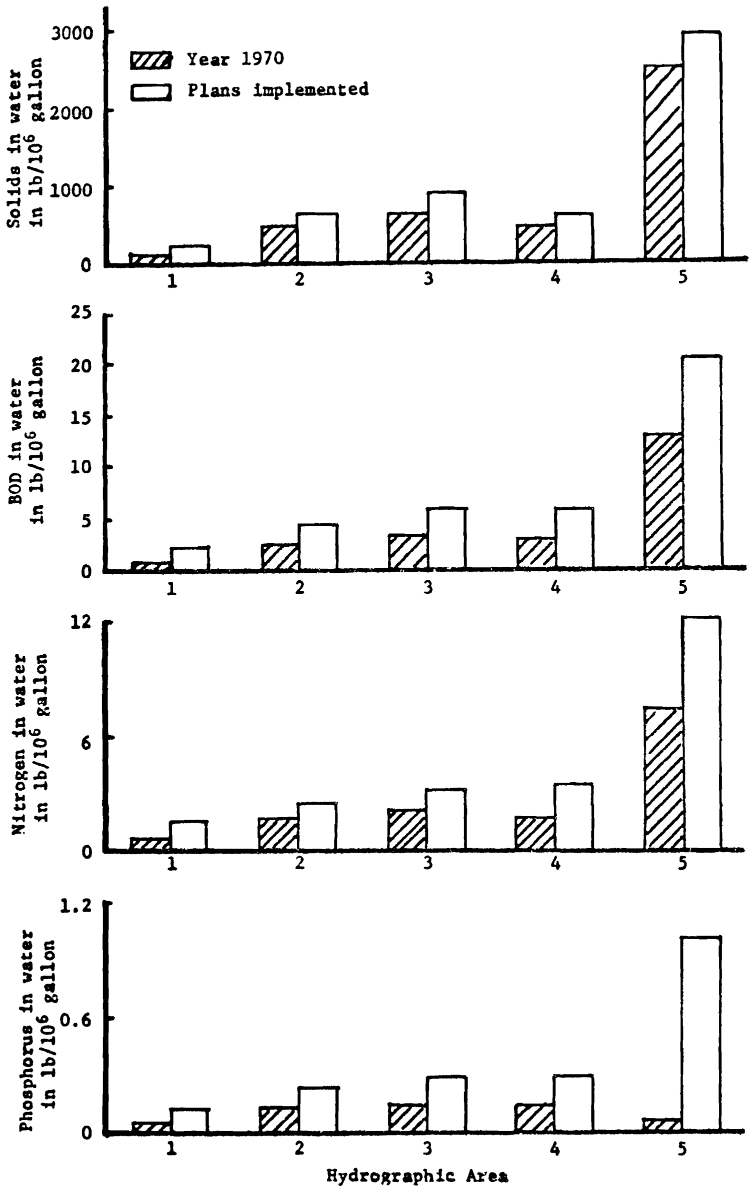


Figure 6. Water Quality Indicators

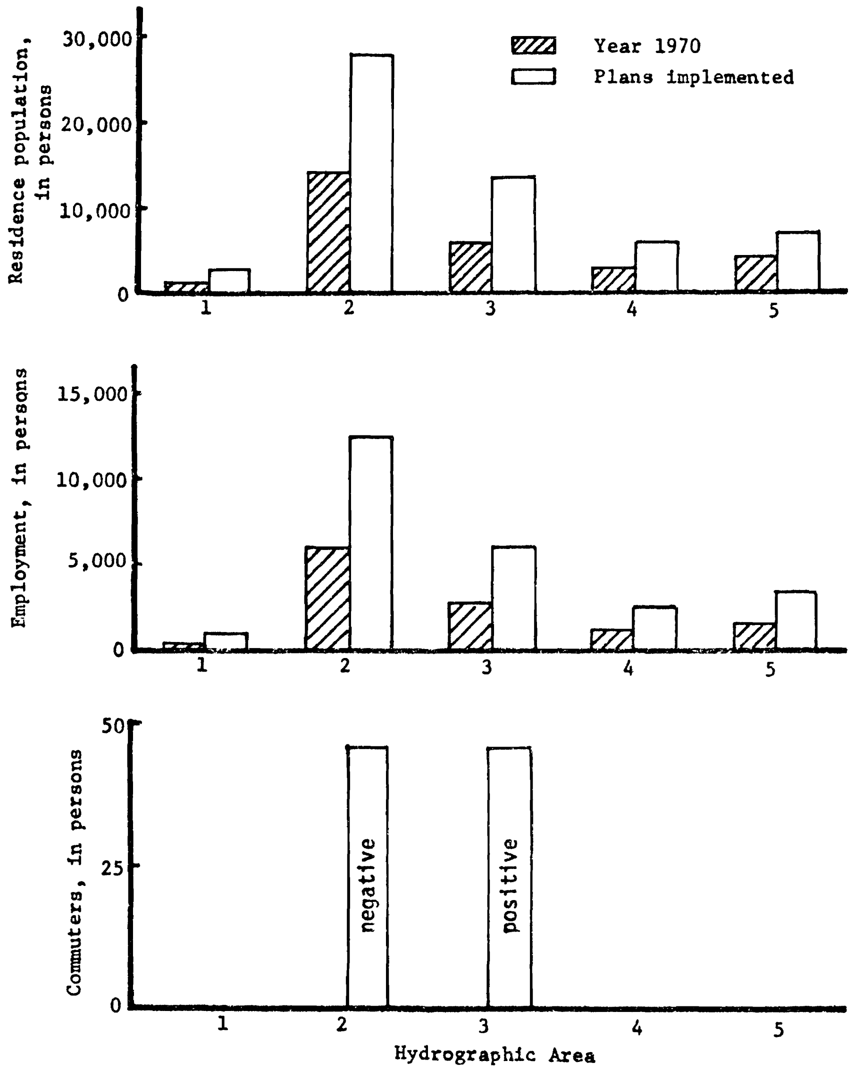


Figure 7. Social Indicators

Step 0: Actual base year industry output, resources and population in each hydrographic area are used as input to check resources adequacy. This step is needed to calibrate the model in terms of gross errors in input data or any other human errors. Output (see Figure 8) from this run will also supply information on the availability of resources (see surplus resource) for future growth.

The slack activity (or **surplus resource**) column indicates there is room to grow without modifying resources now. The next step is to find out if it is possible to grow to the projected level without running into resource shortages.

Step 1: Following past growth trends in each hydrographic area and restraining the population of each area within the projected ceiling, the output (Figure 9) indicates that industries such as 01, 02, 03 etc. (all industries at LL or BS in Figure 9) cannot grow to the needed level because of resources shortage.

The output shown in Figure 10 identified the depleted resources, listed under "Row." The unit cost column shows the impact of increasing or decreasing one unit of these resources in the gross Kauai product, expressed as 10^4\$. For example, \$65.9 (0.00659×10^4) of gross Kauai product can be obtained by adding one acre of total area to Area 1. Model output in Figure 9 shows, in general, that total land and sediment are seriously limiting growth if present quality of life and water quality levels must be maintained. Because it is impossible to increase the total area of any hydrographic area, the

RESOURCE ALLOCATION

SECTION 1 - ROWS

NUMBER	...ROW.. (Resource Type)	AT	...ACTIVITY... (Resource Used)	SLACK ACTIVITY (Resource Surplus)	..
1	K1WA01	BS	1395.53194	823604.46806	
2	K1WA02	BS	1411.48683	889588.51317	
3	K1WA03	BS	1644.60957	1012355.39043	
4	K1WA04	BS	1755.85766	1012244.14234	
5	K1WA05	BS	2133.76002	987866.23998	
6	K1WA06	BS	2135.37627	750864.62372	
7	K1WA07	BS	2135.06225	933864.93775	
8	K1WA08	BS	2314.14346	864685.85654	
9	K1WA09	BS	2124.40794	651875.59206	
10	K1WA10	BS	1837.41503	898162.58497	
11	K1WA11	BS	1647.94559	988352.05441	
12	K1WA12	BS	1435.73088	899564.26912	
13	K1UL	BS	3513.04068	.05932	
14	K1PL	BS	33.09822	.10178	
15	K1TL	UL	94000.00000	.	
16	K1SL	BS	.	.	
17	K1AL	BS	803.43450	396.56550	
18	K1HL	BS	10107.51538	9927.48462	
19	K1SD	UL	14820.39800	.	
20	K1BD	BS	162.31732	.08268	
21	K1NI	BS	89.61812	.08188	
22	K1PH	BS	8.09556	.10444	
23	K2WA01	BS	234165.56545	371834.43455	
24	K2WA02	BS	249146.39226	209853.60774	
25	K2WA03	BS	281918.20733	261081.79267	

SYMBOLS:

K1WA01: Kauai, Area 1, Water, January
UL: Urban land in acres
PL: Beach Park " "
TL: Total Area " "
SL: Sugarcane land in acres
AL: Pineapple and other agriculture land in acres
HL: Pastureland in acres
SD: Sediment in tons
BD: BOD in tons
NI: Nitrogen
PH: Phosphor

Figure 8. Partial Output of Step

	Industry Name	At	Growth Ceiling	Projected Growth
112	INDUS01	LL	.	.20000
113	INDUS02	LL	41.00000	51.17000
114	INDUS03	UL	357.10000	357.10000
115	INDUS04	LL	4054.00000	4117.75000
116	INDUS05	LL	85.00000	457.69000
117	INDUS06	UL	46.19000	46.19000
118	INDUS07	UL	358.42000	358.42000
119	INDUS08	UL	17.00000	17.00000
120	INDUS09	UL	32.38000	32.38000
121	INDUS10	UL	99.35000	99.35000
122	INDUS11	LL	53.00000	194.64000
123	INDUS12	UL	283.78000	283.78000
124	INDUS13	UL	248.15000	248.15000
125	INDUS14	UL	450.63000	450.63000
126	INDUS15	UL	724.92000	724.92000
127	INDUS16	UL	180.65000	180.65000
128	INDUS17	UL	19.42000	19.42000
131	INDUS20	UL	367.48000	367.48000
132	INDUS21	UL	490.10000	490.10000
137	INDUS26	UL	266.66000	266.66000
143	INDUS32	UL	3844.56000	3844.56000
144	INDUS33	LL	63.00000	282.57000
145	INDUS34	LL	5.00000	38.57000
146	INDUS35	UL	257.27000	257.27000
147	INDUS36	UL	516.00000	516.00000
148	INDUS37	LL	162.00000	904.72000
149	INDUS38	UL	1149.73000	1149.73000
150	INDUS39	UL	1436.68000	1436.68000
151	INDUS40	UL	874.67000	874.67000
152	INDUS41	BS	4039.32081	5583.62000
153	INDUS42	UL	1571.00000	1571.00000
154	INDUS43	UL	881.38000	881.38000
155	INDUS44	UL	567.84000	567.84000
156	INDUS45	UL	21513.00000	21513.00000
157	INDUS46	UL	790.07000	790.07000
158	INDUS47	LL	557.00000	3011.87000
159	INDUS48	UL	1356.36000	1356.36000
160	INDUS49	LL	135.00000	561.40000
161	INDUS50	UL	2984.55000	2984.55000
162	INDUS51	LL	188.00000	449.66000
163	INDUS52	LL	38.00000	246.47000
164	INDUS53	UL	870.24000	870.24000
165	INDUS54	UL	503.28000	503.28000

Figure 9. Maximum Economy Growth Under Base Year Resource Supply

RESOUPCE ALLOCATION

'ION 1 - ROWS AT LIMIT LEVEL

'BER	...ROW.. (Res. Type)	AT	...ACTIVITY... (Resource Used)	..LOWER LIMIT. ..UPPER LIMIT. (Supply Limit)	LOWER ACTIVITY UPPER ACTIVITY (Effective Range of Unit Cost)	...UNIT COST.. ...UNIT COST.. (Marginal Resource Return)
15	K1TL	UL	93999.93832	NONE 93999.93832	93998.84554 94001.52549	.00659- .00659
19	K1SD	UL	14820.39138	NONE 14820.39138	14818.77436 14842.44006	.13050- .13050
37	K2TL	UL	83699.97992	NONE 83699.97992	83696.81133 83702.61812	.18353- .18353
38	K2SL	UL	20699.99379	NONE 20699.99379	20698.70940 20701.34130	.00001- .00001
41	K2SD	UL	39199.98657	NONE 39199.98657	39198.36956 39201.52783	.13050- .13050
54	K3WA 10	UL	157399.89586	NONE 157399.89586	157178.33277 157412.45887	.00000- .00000
59	K3TL	UL	50499.98653	NONE 50499.98653	50496.03545 50503.27627	.14459- .14459
61	K3AL	UL	.	NONE .	. .49718	.00000- .00000
63	K3SD	UL	23693.99018	NONE 23693.99018	23688.58151 23710.12597	.13050- .13050
81	K4TL	UL	74999.98253	NONE 74999.98253	74987.31320 75018.07513	.03612- .03612
85	K4SD	UL	19708.40124	NONE 19708.40124	19707.58681 19708.98159	.13051- .13051
93	K5WA05	UL	143548.99500	NONE 143548.99500	136633.55077 143608.85568	.00000- .00000
103	K5TL	UL	49799.98506	NONE 49799.98506	49794.75161 49800.67950	.03543- .03543
104	K5SL	UL	10499.99685	NONE 10499.99685	10498.54185 10503.09879	.05216- .05216
105	K5AL	UL	.	NONE .	. .49718	.30013- .30013
108	K5BD	UL	140.84996	NONE 140.84996	133.21021 140.92539	34.79917- 34.79917

Figure 10. Output Indicating Scarce Resources and Their Impact on Growth

logical move is to lower density, related quality of life conditions, and water quality requirements.

Step 2: The new model output, as a result of sacrificing the environment, again identified nine new resource bottlenecks to growth (see Figure 11). It is possible to increase them simultaneously to achieve maximum growth. However, for pedagogic reasons, it was decided to transfer water only from Area 2 to Area 3. Although Figure 11 showed that water was depleted only for the month of August, invetigation of water utilization (very low surplus in May-July and September-October, Figure 12) in all months and all areas indicates the desirability of a larger scale transfer.

Step 3: As a result of the water transfer described as Action 3 (Table 5), shortage of urban land in Areas 2, 3, and 4 becomes a severe growth bottleneck (see Figure 13). A return of gross product of $15,244.0 and $9,087.0 for each extra acre of urban land can be realized for Areas 2 and 3, respectively. The column "upper activity" also shows the extra return can be obtained at least for a maximum increase of 26 acres and 8 acres for Areas 2 and 3. Approximately .47 million dollars gross product was expected from this action.

Step 4: Model output displayed in Figure 14 confirms it is true that guiding industry growth spatially could mean more growth with less investment or sactifice of environment. The variables K155, K455 and K555 under column (Figure 14) denote resident populations in Areas 1, 4, and 5. The corresponding reading below unit cost shows that extra

RESOURCE ALLOCATION

SECTION 1 - ROWS AT LIMIT LEVEL

NUMBER	...ROW.. (Resource Type)	AT	...ACTIVITY... (Resource Used)	SLACK ACTIVITY (Surplus Resources)	..LOWER LIMIT. ..UPPER LIMIT. (Resource Supply)	LOWER ACTIVITY UPPER ACTIVITY (Effective Range for Unit Cost)	...UNIT COST.. ...UNIT COST.. (Marginal Resource Return)
35	K2UL	UL	7753.99530	.	NONE 7753.99530	7729.74389 7778.40919	1.55780- 1.55780
37	K2TL	UL	167399.89956	.	NONE 167399.89956	164136.11586 167916.99196	.03962- .03962
38	K2SL	UL	20699.99379	.	NONE 20699.99379	20695.42499 20707.12628	7.75552- 7.75552
52	K3WA08	UL	182499.92684	.	NONE 182499.92684	182265.99444 182513.94060	.54617- .54617
81	K4TL	UL	149999.89473	.	NONE 149999.89473	134072.12629 152525.04268	.01322- .01322
82	K4SL	UL	4799.99887	.	NONE 4799.99887	4798.83652 4807.13136	7.75552- 7.75552
96	K5WA08	UL	136029.96439	.	NONE 136029.96439	134610.76786 136298.80797	.00000- .00000
104	K5SL	UL	10499.99685	.	NONE 10499.99685	10498.54185 10507.12934	7.75549- 7.75549
105	K5AL	UL	.	.	NONE .	. 101.28148	. .
112	INDUS01	LL	.	.20000	.00000- .20000	.34837- .37238	159.16442 159.16442-

Note: Resources such as K2UL, K2TL, etc. at UL indicates resources being exhausted.

Figure 11. Scarce Resources and Their Impact

...ROW..	AT	...ACTIVITY... (Water Consumption)	SLACK ACTIVITY (Surplus Water)
K1WA01	BS	3190.37225	821809.62775
K1WA02	BS	3273.75366	887726.24634
K1WA03	BS	3782.53005	1010217.46994
K1WA04	BS	3972.26984	1010027.73016
K1WA05	BS	4768.68101	985231.31899
K1WA06	BS	4699.79911	748300.20089
K1WA07	BS	4760.21726	931239.78274
K1WA08	BS	5000.73671	861999.26329
K1WA09	BS	4630.93317	649369.06683
K1WA10	BS	4050.85352	895949.14648
K1WA11	BS	3632.70870	986367.29130
K1WA12	BS	3221.81446	897778.18554
K2WA01	BS	256984.95958	349015.04042
K2WA02	BS	272571.90130	186428.09870
K2WA03	BS	308977.74586	234022.25414
K2WA04	BS	312053.45413	212946.54587
K2WA05	BS	363434.20761	212565.79239
K2WA06	BS	344159.00633	90840.99367
K2WA07	BS	360588.89826	122411.10174
K2WA08	BS	348030.68892	167969.31108
K2WA09	BS	330335.01388	137664.98612
K2WA10	BS	297981.26653	221018.73347
K2WA11	BS	267141.69419	257858.30581
K2WA12	BS	248085.55255	309914.44745
K3WA01	BS	137220.73815	90779.26185
K3WA02	BS	146083.75854	45916.24146
K3WA03	BS	165244.30988	59755.69012
K3WA04	BS	166143.26442	4856.73558
K3WA05	BS	192801.22921	98.77079
K3WA06	BS	181672.97464	27.02536
K3WA07	BS	191150.10038	49.89962
K3WA08	UL	182500.00000	.
K3WA09	BS	173787.45614	12.54386
K3WA10	BS	157387.03938	12.96062
K3WA11	BS	141092.89077	47907.10923
K3WA12	BS	131772.60281	90227.39719
K4WA01	BS	85621.55902	604378.44098
K4WA02	BS	91036.79847	418963.20153
K4WA03	BS	103051.88660	511948.11340
K4WA04	BS	103771.03885	406228.96115
K4WA05	BS	120570.26470	299429.73530
K4WA06	BS	113804.54650	156195.45350
K4WA07	BS	119568.13501	262431.86499
K4WA08	BS	114584.63322	275415.36678
K4WA09	BS	108991.52985	146008.47015
K4WA10	BS	98571.76328	246428.23672
K4WA11	BS	88367.86437	406632.13563
K4WA12	BS	82370.29172	622629.70828
K5WA01	BS	101663.55741	168336.44259
K5WA02	BS	108097.17335	91702.82665
K5WA03	BS	122361.42280	118838.57720
K5WA04	BS	123210.18772	76589.81228
K5WA05	BS	143151.50003	397.58997
K5WA06	BS	135112.40755	462.59245
K5WA07	BS	141960.67513	399.32487
K5WA08	UL	136030.00000	.
K5WA09	BS	129394.11863	535.88137
K5WA10	BS	117028.15823	1367.84177
K5WA11	BS	104913.67662	89086.32338
K5WA12	BS	97798.31382	178701.68618

Figure 12. Water Consumed and Surplus

RESOURCE ALLOCATION

SECTION 1 - ROWS AT LIMIT LEVEL

NUMBER	...ROW.. (Resource Type)	AT	...ACTIVITY... (Resource Used)	SLACK ACTIVITY (Surplus Resources)	..LOWER LIMIT. ..UPPER LIMIT. (Resource Supply)	LOWER ACTIVITY UPPER ACTIVITY (Effective Range for Unit Cost)	...UNIT COST.. ...UNIT COST.. (Marginal Resource Return)
35	K2UL	UL	7753.99530	.	NONE 7753.99530	7729.74389 7778.40919	1.55780- 1.55780
37	K2TL	UL	167399.89956	.	NONE 167399.89956	164136.11586 167916.99196	.03962- .03962
38	K2SL	UL	20699.99379	.	NONE 20699.99379	20695.42499 20707.12628	7.75552- 7.75552
52	K3WA08	UL	182499.92684	.	NONE 182499.92684	182265.99444 182513.94060	.54617- .54617
81	K4TL	UL	149999.89473	.	NONE 149999.89473	134072.12629 152525.04268	.01322- .01322
82	K4SL	UL	4799.99887	.	NONE 4799.99887	4798.83652 4807.13136	7.75552- 7.75552
96	K5WA08	UL	136029.96439	.	NONE 136029.96439	134610.76786 136298.80797	.00000- .00000
104	K5SL	UL	10499.99685	.	NONE 10499.99685	10498.54185 10507.12934	7.75549- 7.75549
105	K5AL	UL	.	.	NONE .	. 101.28148	. .
112	INDUS01	LL	.	.20000	.00000- .20000	.34837- .37238	159.16442 159.16442-

Note: Resources such as K2UL, K2TL, etc. at UL indicates resources being exhausted.

Figure 13. Scarce Resources

return could be expected by realizing these population ceilings. For example, in Area 1 a return of $4,174.23 gain per person could be expected if the resident population is allowed to exceed the ceiling of 2,000 persons. This estimate holds for a maximum increase of ((236.3-199.9) x 10) or 364 people. Therefore the population ceilings of Areas 1,4, and 5 were increased for the next run.

Step 5: Model output again indicates more relaxation on these population ceilings. Since output is similar to that displayed in Figure 14, it is not included here.

DISCUSSION

The Kauai County example used in this report only considered eleven resources; namely --

1) water,
2) urban land,
3) park land,
4) total land of the area,
5) sugarcane land,
6) pineapple and diversified agriculture land,
7) pasture land,
8) sediment carrying capacity,
9) BOD carrying capacity,
10) nitrogen carrying capacity, and
11) phosphorus carrying capacity.

However, the model can handle virtually any number of restrictions.

RESOURCE ALLOCATION

NUMBER	.COLUMN.	AT	...ACTIVITY...	..INPUT COST..	..LOWER LIMIT. ..UPPER LIMIT.	LOWER ACTIVITY UPPER ACTIVITY	...UNIT COST.. ...UNIT COST..
(Population			(Level or Size)		(Population Limit)	(Effective Range for Unit Cost)	(Marginal Population Return)
229	K155	UL	199.99996	.	118.19998 199.99997	87.48340 236.35595	4.17419- 4.17419
394	K455	UL	589.99993	.	317.29977 589.99996	576.45690 634.58619	3.40822- 3.40822
449	K555	UL	719.99983	.	415.89980 719.99987	679.71852 804.77102	4.17416- 4.17416

Figure 14. Population Ceiling Projected on Basis of Past Growth is Identified as Growth Bottleneck

Any resource, with a known per capita demand and per unit industry consumption, can be checked against an expected supply. Harbor capacity, main transportation arteries, air pollution, and energy could be incorporated next. Capital also can be treated as a resource and considered simultaneously with the other constraints.

Objective Other Than Gross Product

Maximizing the gross product of Kauai constitutes the primary planning goal of the example. It does not have to be so in every plan. In an energy lacking region it may be desirable to develop a plan which consumes the least energy. A capital lacking or abundant region may opt to develop a growth plan which either minimizes or maximizes capital requirement. In a high unemployment area the planning objective can become more job opportunities. Selection of the objective can be easily taken care of by the model.

Dynamic Versus Static Planning

The technical coefficient, A_{ij}, in expression (1a) remains relatively stable for a well developed region. Therefore, it would not be necessary to modify A_{ij} very frequently. In developing regions, this may not be so.

To include technological change in the analysis, the planning horizon should be shortened accordingly. It is possible to build into the program a mechanism to update A_{ij} in fixed intervals. The drawback of this automatic updating makes checking of model solution more difficult. Therefore, a stepwise or discrete planning interval approach may be more desirable. It may not be completely dynamic.

But the ease of checking is more desirable and conducive to the building of confidence in the model.

Cooperative Planning Tools

The discrete iterative approach also has the advantage of allowing people to contribute input. In fact, the greatest value of this model lies in its ability to provide a common ground on which a truly cooperative planning effort can be effectively conducted. The complexities of planning in terms of the number of scientific disciplines and the number of multiple groups of diverse interests require such a vehicle for interaction and communication. The speediness of the present model in evaluating impact of any proposition or idea makes it extremely suitable for this purpose.

Without a tool of this nature, it is inconceivable that truly multi-objective planning can be effectively carried on in a multi-decision maker environment. The present lack of this type of tool may well account for the closed door planning which has generated many plans with very few ever being implemented.

Although the Kauai example did not include any post-optimal analysis which is usually performed after an optimal plan is obtained, these procedures are available from this model. Indeed, the model evaluation software IBM-MPSX has one of the most powerful built-in post-optimization features available.

Appendix I. THE MODEL AND ITS COEFFICIENT

Economic Needs and Interindustry Relationship

$$\sum_{ij} (I - A_{ij})\ X_{ij} \geqq B_{\ell} \text{-----------------} (1a)$$

$$\sum_{ij} (I - A_{ij})\ X_{ij} \leqq B_{u} \text{----------------} (1b)$$

where

I : Identity matrix

A : A matrix or technical coefficient matrix of ij th area (i index may be used to identify island or region and j index the hydrographic area of the ith island or the ith region. A study area is divided into many ij areas)

X_{ij}: A column matrix consists of n components $X_{ij1}, X_{ij2}, \ldots X_{ijm} \ldots X_{ijn}$

where

X_{ijm} is the total output of the mth industry located in the ijth region and n is the total number of different types of industry in the study area.

B_{ℓ} : A column matrix consists of n components $b_{\ell 1}, b_{\ell 2}, \ldots, b_{\ell m} \ldots b_{\ell n}$

where

$b_{\ell m}$ is the present or base year total final demand of the mth industry in the total study area.

B_{um}: A column matrix consists of n components

$b_{u1}, b_{u2}, \ldots, b_{um}, \ldots, b_{un}$

which are predicted total final demands of all n industries for a given project year in the total study area.

Water Resource and Economic Needs

$$\sum_{k}^{n+1} W_{k\ell} X_{ijk} \leq b_{ij\ell} \text{ for all } \ell, \text{ i and j} \qquad \text{------(2)}$$

where

W_K : the water demand of industry k during the ℓth month, in 10^4 gallons/10^4 \$ output.

b_{ℓ} : Available water in the ℓth month of the ijth area.

X_{ijk} : the output of the kth industry in the ijth area in 10^4\$.

X_{ijn+1} : the population living in the ijth area (excluding people commuting to ijth area for employment).

Water Quality and Economic Needs

$$\sum_{k}^{n} S_{ijkr} \cdot X_{ijk} \leq S_r \cdot b_{ij} \text{ -------------(3)}$$

where S_{ijkr} : the annual discharge of rth pollutant from the kth industry in the ijth area, in tons/10^4 \$

S_r : Maximum allowable rth pollutant in the water, in tons/10^4 gallons of water

b_{ij} : the amount of annual surface runoff of water of the ijth area, in 10^4 gallons

r : denotes the pollutants such as:

1) sediment
2) phosphate
3) nitrate, etc.

Quality of Life and Economic Needs

$$\sum_{k}^{n+1} q_{ijkr} x_{ijk} \leq b_{ijr} \text{ for all } i, j, r \quad \text{--(4)}$$

where

q_{ijkr}: the amount of rth resource in ijth area such as open space which must be allocated to each unit of output of kth industry to guarantee a prefered urban density, availability of park and open space, in acres per 10^4 $ output

b_{ijr}: available rth resource such as urban land, park area, in acres.

Land Resources For Agriculture Production

$$\sum_{k}^{n} a_{ijkr} X_{ijk} \leq b_{ijr} \text{ for all } i,\ j,\ r \text{ ---------}(5)$$

where

a_{ijkr}: the amount of rth type of land needed for producing one unit of output of the kth industry, in acre per 10^4\$

b_{ijr}: the available rth land resource in ijth area, in acre

Constraint (5) can be expanded to include other resources or infrastructures which can be identified to each ijth area. The adequacy of harbor capacity, shoreline, etc., can be considered by using constraint (5)

Population Distribution Needs

$$\sum_{k}^{n+1} p_k x_{ijk} \geqq p_{ij\ell} \text{ for all } ij \text{ ----------} \quad (6a)$$

$$\sum_{ij} \sum_{k}^{n+1} p_k x_{ijk} \leqq p_{iju} \text{ ----------------} \quad (6b)$$

where

p_k : population generated by each unit output of industry k , in 10 persons/10^4 \$.

$p_{ij\ell}$: Existing or base year population in ijth area, in 10 persons

p_{iju} : projected population at the end of planning year, in 10 persons

Industry Size Preference

$$X_{ijk} \geq h_{ijk\ell} \text{ ----------------(7a)}$$

$$X_{ijk} \leq hijku \text{ ----------------(7b)}$$

$$X_{ijk} = hijk \text{ ----------------(7c)}$$

for all ijk

where

$h_{ijk\ell}$: the desired minimum size of the kth industry in the ijth area, in 10^4 \$.

hijku : the desired maximum size of the kth industry in the ijth area, in 10^4 \$.

Population Based Industry Location Restraint

Some industries must be located closely to where the population is. Industries such as personal services belong to this class. Other types of industry, such as construction, also falls into this category. The industry output are primarily generated for meeting the need of the population located closely. A restraint of following form will serve this purpose:

$$p_m X_{ijm} - \sum_{k}^{n+1} p_k X_{ijk} \geq o \text{ for all } ij \text{ and } m \text{ ----------(8)}$$

where

p_k : population generated by each unit output of industry k, in 10 persons/10^4 \$

p_m : The size of the population whose need for industry m output can be met by one unit of m industry output, in 10 person per 10^4 \$

X_{ijk} : X industry output in the ijth area.

Commuting Pattern Constraint

When hydrographic areas are small in size, it is very common that people live in one hydrographic area and commute daily to other hydrographic areas to work. This is especially true in metropolitan areas. When planning future economic growth, this factor must be carefully considered to avoid confusion and chaos in terms of traffic, availability of recreation and other facilities. This consideration can be explicitly considered by (8-a):

$$\sum_{j \epsilon C_I} [\sum_{k}^{n} p_k X_{ijk} - p_{n+1} X_{ijn+1}] = 0.0 \text{ --------------------(8a)}$$

where

C_I : Ith population integrated hydrographic areas.

ϵ : means "belongs."

X_{ijn+1}: population lives in the ijth area.

Objective Function:

$$Z = \sum_{ij} \sum_{k} C_{ijk} X_{ijk} \quad \text{----------------(9)}$$

where

C_{ijk} : the ratio of total final demand to total output of the kth industry in the ijth area, in decimal.

Z : gross product of the region under study due to direct industry output.

DERIVATION OF COEFFICIENTS

Final Demand b_{um} and b_{lm}

The right hand side coefficients of inequalities (1a) and (1b) are related:

$$b_{um} = b_{\ell m} (1+g_{fm})^{I} \text{ ---------------------} (10)$$

where

g_{fm} : the annual final demand growth rate of the mth industry, in decimal

I : End of the planning period from base year, in years.

$b_{\ell m}$: the base year or existing final demand for the m th industry, can be found readily from the transaction table of the input - output study conducted for the study area.

Water Demand $W_{k\ell}$ (eq. 2)

$$W_{k\ell} = d_\ell W_c V_\ell p_k C + W_{dk} e_\ell \text{ for all } k\&\ell \text{ --------------(11)}$$

$$W_{n+1,\ell} = d_\ell W_c V_\ell \ (1-C) \text{ for all } \ell \text{ ---------------(11-a)}$$

where

d_ℓ : number of days in the ℓth month

W_c : daily mean value of per capita water consumption, in 10^4 gallons

V_ℓ : ratio of per capita water consumption in the ℓth month to the mean water consumption value, in decimal.

W_{dk} : water (other than human consumption) used directly by the kth industry such as irrigation for agriculture, in 10^4 gallons/10^4 \$ - year

e_ℓ : fraction of evaporation of the total annual evaporation in ℓth month, in decimal.

p_k : population generated by each 10^4 \$ output of the kth industry, 10 persons

C : fraction of per capita water consumption not used at home, in decimal.

Water Quality Coefficients (eq.3)

$$S_{ijkr} = d_{ijtr} \cdot L_{ijkt} \text{ ---------------------- } (12)$$

where

d_{ijtr}: The amount of rth pollutant washed off t type land in the ijth area, in tons/acre - year.

L_{ijkt}: The amount of t type land used per 10^4 \$ output of the kth industry in the ijth area, in acres/ 10^4 \$ - year.

Quality of Life q_{ijkr} (eq. 4)

For urban density,

$$q_{ijkr} = 10.0 . U_{ijd} p_k e_1 e_2 \text{ ---------------------------(13)}$$

$$\text{or } = 10.0 . V_{ijd} p_k e_1 e_2$$

$$\text{or } = 10.0 . O_{ijd} p_k e_1 \text{ for all ij \& k (except } k = n+1)$$

$$q_{ij,n+1,r} = 10.0\ U_{ijd}$$

$$= 10.0\ V_{ijd}$$

$$= 10.0\ O_{ijd}(1.0 - e_1) \text{ --------------------(13-a)}$$

where

r = urban, park or open space.

U_{ijd} = the preferred per capita urban land need in the ijth area, in acres/person.

V_{ijd} = the preferred recreation or park land per capita need in the ijth area, in acres/person

O_{ijd} = the preferred open space per capita need in the ijth area, in acres/person.

e_1 = employed to population, in decimal.

e_2 = day time need of the employed to per capita residential need, in decimal.

Land commissions or SCS, USDA are good resources for obtaining information on the available resource b_{ijr}.

Agriculture Land Demand (eq. 5)

The productivity of agriculture land differs from region to region. The coefficient a_{ijkr} in equation (5) is expected to be different for different regions and areas. For areas where land productivity is available, a representative coefficient can be obtained. As an example, the land coefficient for sugarcane industry in an area with its sugarcane land classified as 60% A class, 15% B class, and 25% C class is calculated here. The land requirement for each class or type of land is obtained from table 1. Then the land coefficient, a_{ijkr}, will be

$$15.7 \times 0.6 + 19.2 \times 0.15 + 23.4 \times 0.25 = 18.15 \text{ acres}/10^4\$$$

Table 1. Sugarcane Industry Land Coefficient For Various Land Types

Class/Use	Tons/Ac/Yr	1970 Farm Price	Value/Ac	Acres/$10,000
1(A)	55	$11.58	$637	15.7
2(B)	45	$11.58	521	19.2
3(C)	37	$11.58	428	23.4

Population Coefficients p_k (eq. 6)

$$p_k = C_t t_k/(1+g_k)^I$$

where

C_t = the ratio of the total number of persons supported directly by the kth industry to the kth industry employment, in decimal.

t_k = Number of employment generated by each 10^4 \$. of the kth industry, in 10 persons/10^4 \$. (Self employed and government workers are prorated to each industry in accordance to its employment)

g_k = the annual growth rate of labor productivity of industry k, in decimal.

I = the end of the planning period, in years.

Appendix II. INPUTS TO THE MODEL

Card Group

1) Leontief technical coefficient matrix

   Format (8F10.5)

2) POPUD(I): Population supported by the Ith industry in 10 person/US $10000.0 (54 items).

   Format (8F10.5)

3) IYEAR : Planning period, in years

   Format (I2)

4) GROWTP(I): Annual labour productivity increase of the Ith industry, in decimal.
   (If one person is needed now to produce $10000.0 of Ith commodity and only 0.97 will be needed next year, then GROWTP(I) = $\frac{1.0-0.97}{1.0}$ = 0.03)

   Format (8F10.5)

5) ISNAME = Island or major area name
   RSNAME = Resource name
   ANAME = Hydrographic or minor area name (1, 2,... 8,9,10)
   TINTER = Interval name (01, 02, ..., 12)

   Format (8A1, 11A2, 10A1, 12A2)

6) IDNAME(I)= The Ith industry name (01, 02, ..., 54, 55)

   Format (40A2)

7) NA(I): No. of hydrographic or minor areas of the Ith major area.

ISLAD: No. of Island or major areas.

NR: No. of resources

Format (3I1, 2I2)

8) EXPOPU: Projected regional (all major areas) population at end of planning period, in 10 persons

EXPOPL: Population at the beginning of planning period, in 10 persons

Format (8F10.5)

9) AMATRIX: Coefficient of the objective function

Format (8F10.5)

10) RWS (I,J,K): Water supply, in 10^6 gallons, in the Kth month, jth minor area, Ith major area.

Format (8F10.5)

11) RS (I,J,N): Nth resource supply in the jth minor area, Ith major area (land resources in acres and pollutant in tons)

Format (8F10.5)

12) FINALD(I): The predicted final demand, in 10^4\$, of the Ith industry.

13) RANG(I): Present (or base year) final demand of the Ith industry, in 10^4\$.

Format (8F10.5)

14) FLOW(N,I): FLOW (population) control of the Nth major area and the Ith minor area

Format (10A1,...)

15) NPG(N): No. of integrated population area groups in the Nth major area.

Format (40I2)

16) IP(I,J): No. of minor areas in the Jth group in the Ith major area.
(Note: minor areas in each group must be consecutively numbered, i.e., 1, 2, 3 or 2, 3, 4, or 3, 4 but not 1, 3)

Format (40I2)

17) INPUT to SUBROUTINE WATERD
(Card groups 17 and 18 must be provided for each hydrographic or minor areas)

Format (8F10.2)

17-1) EPRATI = Employed person/population ratio
DAYUSE = Office use of water in fraction of total daily use

Format (8F10.2)

17-2) EVAPVA = Monthly average evaporation in percent.

Format (8F10.2)

17-3) VARIAT(I) = Monthly variation of water consumption of the Ith month, in fraction of average water consumption.

Format (8F10.2)

17-4) WACPA = Daily average per capita water consumption, in gallons/day.

WA(I) = Total annual direct water consumption of the Ith industry; in 10^4 gallons/$10000.0.

Format (8F10.2)

18) INPUT TO SUBROUTING LAND

18-1) ULCPA = Per capita urban land needs, in acres
PLCPA = Per capita park land need, in acres
TLCPA = Per capita total land need, in acres
SLD = Sugarcane land/10,000.0 $ US, in acres
ALD = Pineapple land/10,000.0 $ US, in acres
HLD = Pasture land/10,000.0 $ US, in acres
EPRATI = Employed person/population
OURATI = Office resource need/Home need (per person)

Format (8F10.4)

18-2) POLUT (J,I): Pollutant J in tons/acre from Ith land (UL, PL, SL, etc.)

Format (8F10.5)

19) (Bound Section)*

19-1) TYPE = Type of bound (FX, LO,...)
BNAME1 = First part of bound name
BNAME2 = Second part of bound name
COLNAM = Column name on which the bound is imposed.

Format (A2, A4, 2A2)

19-2) NO = No. of bound

Format (40-I2)

PP(J) = The number of the industries which require bound.
VALUE (I) = Value of the Ith bound.

Format (8F10.5)

*Three types of bound are provided to:

a. eliminate certain industries from an area
(FX bound)

b. guarantee existing industry and population (industry 55) will not be moved
(LO bound)

c. guarantee population and industries will not exceed projected or planned amount
(UP bound)

Appendix III. GUIDELINE FOR USING THE MODEL

1) Obtain an initial feasible solution:

   a) Use minimization instead of maximization.

   b) Don't use real resource supply. Otherwise, other data (input) are real. Make resource supply as large as space will allow. Population lower bound (base year) for each area should be real.

   c) The out/puts (model) are to be compared with known resource supply which should be larger or at least equal to the demand (resource) indicated on the model output. Otherwise, it indicates error.

2) Obtain maximum output without a plan.

   a) Use real resource supply instead and run the model for each island separately to maximize output (state GNP).

   b) Add the output values for all runs. This is the maximum possible growth a natural growth pattern can achieve.

3) Obtain maximum output under optimal directed growth:

   Use same input data but run the model for all islands (not separately). Compare the Z value and the maximum output obtained in step 2. The difference is the benefit due to directed growth action. Enter in the appropriate column on work sheet.

4) Check if economic demand is met. Identify resource shortage and develop promising actions (trial plan):

   a) If economic demands not met, adjust if permitted. When not permitted, proceed to (b).

b) If shortage is not severe, the benefit of each promising action can be obtained directly from the output. In fact, an optimal plan can be obtained without further running the model.

c) When shortages are severe, the trial plan should be tested by running the model again.

WORK SHEET

(1) Resources or demand shortage	(2) Type of action	(3) Actions proposed to remove resource shortage				(4) Cost & benefit associated with the actions				Remarks
		Directed growth pattern	Resource transfer	New or recycled resource	Technology improvement	Adjust demand	Gross benefit 10^6\$	Cost 10^6\$	Net benefit	

1) Demand means economic demand expressed in terms of industry.
2) Types of action are EC (economic), EQ (environmental), SO (social).

Appendix IV. PROGRAMS FOR MODEL GENERATION AND OPTIMIZATION

```
*12.51.00 JOB 377 ** ENDED JOB #2928 - KAUI      ,      55.5
N 12.51.01 JOB 377 END EXECUTION.
//KAUI     JOB  (2928,1KI,50S,3KL,130KR),'T. LIANG'                          JOB 377
//  EXEC FORTCLG,REGION=130K
//SYSIN  DD   *
************************** J O B   P A R A M E T E R S ********************
* JOB # * CPU TIME * I/O REQUESTS * MAX REGION *   LINES  *   CARDS  * FORMS * COF
* 2928  *      50 S *       1024   *    130K    *     3072 *     1000 *  STD  *
*********************************************************************************
IEF142I - STEP WAS EXECUTED - COND CODE 0000
IEF142I - STEP WAS EXECUTED - COND CODE 0000
//GO.FT01F001 DD UNIT=(9TRK,,DEFER),VOL=SER=LPDATA,
//        DISP=(NEW,KEEP),LABEL=(,NL),
//         DCB=(RECFM=FB,LRECL=61,BLKSIZE=24400)
//GO.FT02F001  DD  DSNAME=KAUI2928,DISP=SHR
//GO.SYSIN  DD   *
IEF142I - STEP WAS EXECUTED - COND CODE 0000
```

```
                C
                C INPUT SECTION
                C
 0001                 DIMENSION POPUD(56 ),A(54,55)
 0002                 REWIND 2
 0003                 DO 603 I=1,54
 0004             603 READ(2,104) (A(I,J),J=1,54)
 0005                 DO 604 I=1,54
 0006                 DO 604 J=1,54
 0007                 IF(I .EQ. J) A(I,J)=A(I,J) -1.0
 0008             604 A(I,J) = -A(I,J)
 0009                 DO 1603 I=1,54
 0010            1603 A(I,55)=0.0
 0011                 READ(5,104) (POPUD(I),I=1,55)
 0012                 READ(5,850) IYEAR
                C  GROWTP IS PRODUCTIVITY GRPWTH RATE PER YEAR ,IN DECIMAL.
 0013                 DIMENSION GROWTP(56)
 0014                 READ(5,104) (GROWTP(I),I=1,55)
 0015             850 FORMAT(I2)
 0016                 DO 851 II=1,54
 0017                 DO 851 I=1,IYEAR
 0018             851 POPUD(II) = POPUD(II) / (1.0 + GROWTP(II))
 0019                 WRITE(6,105) (POPUD(I),I=1,54)
 0020                 REWIND 1
 0021                 REAL ISNAME(8),IDNAME( 55)
 0022                 DIMENSION WD(55,12 )
 0023                 DIMENSION RNAME(11),ANAME(10),TINTER(12)
 0024                 READ(5,106) (ISNAME(I),I=1,8),(RNAME(I),I=1,11),
                     $     (ANAME(I),I=1,10),(TINTER(I),I=1,12)
 0025             106 FORMAT(8A1,11A2,10A1,12A2)
 0026                 READ(5,107) (IDNAME(I),I=1,55)
 0027             107 FORMAT(40A2)
 0028                 DIMENSION NA(8)
 0029                 READ(5,108) (NA(I),I=1,8) ,ISLAD,NR
 0030                 DO 3002 I=1,8
```

```
0031            IF(NA(I) .LE. 0) NA(I)=10
0032       3002 CONTINUE
0033            READ(5,104) EXPOPU,EXPOPL
0034            EXPOPL = EXPOPU -EXPOPL
0035        108 FORMAT(8I1,2I2)
0036        104 FORMAT(8F10.5)
0037        105 FORMAT(' ',12F10.5)
0038            DIMENSION RD(11,55)
0039            DIMENSION AMATRX(55)
0040            READ(5,104)  (AMATRX(I),I=1,55)
          C RWS(I,J,K)=WATER SUPPLY IN THE KTH MONTH JTH AREA,ITH ISLAND
          C (MAX I=54,J=6,K=12 IN 10**6 GALLONS)
0041            DIMENSION RWS(8,6,12), RS(8,6,11)
0042            DO 143 N=1,ISLAD
0043            IAA=NA(N)
0044            DO 143 IA=1,IAA
0045            READ(5,104) (RWS(N,IA,J),J=1,12)
          C CONVERT RWS INTO 10**4 GALLONS/MONTH
0046            DO 143 J=1,12
0047        143 RWS(N,IA,J)=RWS(N,IA,J)*100.0
0048            DO 144 N=1,ISLAD
0049            IAA=NA(N)
0050            DO 144 IA=1,IAA
0051        144 READ(5,104)  (RS(N,IA,J),J=2,NR)
0052            DIMENSION FINALD(54),RANG(54)
0053            READ(5,104) (FINALD(I),I=1,54)
0054            READ(5,104) (RANG(I),I=1,54)
0055            DO 845 M=1,54
0056        845 RANG(M) = FINALD(M) - RANG(M)
          C  POPULATION FLOW CONTROL
0057            DIMENSION FLOW(10,10)
0058             DO 3003 N=1,ISLAD
0059            IAA=NA(N)
0060       3003 READ(5,106)  (FLOW(N,I),I=1,IAA)
          C  POPULATION INTEGRATED GROUPS
0061            DIMENSION IP(8,11),NPG(8)
0062            READ(5,1004) (NPG(J),J=1,ISLAD)
0063            DO 1005 N=1,ISLAD
0064            NO=NPG(N)
0065       1005 READ(5,1004) (IP(N,J),J=1,NO)
          C  NPG(N)=NO OF SUCH GROUPS ON THE NTH ISLAND
          C  IP(N,J)=NO OF AREAS IN THE JTH GROUP ON THE NTH ISLAND
          C THE ONLY READ NOT IN INPUT SECTION IS IN BOUND SECTION
          C  INPUT ARE ALSO FROM THE THREE SUBROUTINE
          C
          C WRITE LABEL SECTION
          C
0066            WRITE(6,112)
0067            WRITE(1,512)
0068        112 FORMAT (' ','NAME',10X,'RESOURCE')
0069        512 FORMAT (     'NAME',10X,'RESOURCE')
          C
          C ROW SECTION
          C
0070        111 FORMAT(' ','ROWS')
0071        511 FORMAT(     'ROWS')
```

```
0072            WRITE(6,111)
0073            WRITE(1,511)
0074            DO 128 N=1,ISLAD
0075            IAA=NA(N)
0076            DO 128 IA=1,IAA
0077            DO 123 J=1,12
0078        123 WRITE(1,513) ISNAME(N),ANAME(IA),RNAME(1),TINTER(J)
0079            NRR=NR-1
0080            DO 128 K=1,NRR
0081        128 WRITE(1,1513)ISNAME(N), ANAME(IA),RNAME(K+1)
0082        513 FORMAT(     1X,'L',2X,2A1,2A2)
0083       1513 FORMAT(     1X,'L',2X,2A1,A2)
0084            WRITE(1,514)
0085        514 FORMAT(     1X,'N',2X,'ZVALUE')
          C INTERINDUSTRY CONSTRAINT ROWS
0086            DO 600 I=1,54
0087        600 WRITE(1,601) IDNAME(I)
0088        601 FORMAT(     1X,'L',2X,'INDUS',A2)
          C POPULATION CONSTRAINT
          C  ROWS CONSIDERING POPULATION IN EACH HYDRO-AREA
0089            DO 800 N=1,ISLAD
0090            IAA=NA(N)
0091            DO 800 IA=1,IAA
0092            WRITE(6,801) FLOW(N,IA),ISNAME(N),ANAME(IA)
0093        800 WRITE(1,802) FLOW(N,IA),ISNAME(N),ANAME(IA)
0094        801 FORMAT(' ',1X,A1 ,2X,2A1,'POPUL',3X,7H'SCALE',3X,'0.01')
0095        802 FORMAT(     1X,A1 ,2X,2A1,'POPUL',3X,7H'SCALE',3X,'0.01')
0096            WRITE(1,620)
0097        620 FORMAT(1X,'L',2X,'POPULAT',3X,7H'SCALE',3X,'0.01')
0098            DO 1010 N=1,ISLAD
0099            NO=NPG(N)
0100            DO 1010 J=1,NO
0101            WRITE(6,1011) ISNAME(N),J
0102       1010 WRITE(1,1012) ISNAME(N),J
0103       1011 FORMAT(' ',1X,'E',2X,A1,'POPULG',I1,2X,7H'SCALE',3X,'0.01')
0104       1012 FORMAT(     1X,'E',2X,A1,'POPULG',I1,2X,7H'SCALE',3X,'0.01')
          C
          C COLOUM SECTION
          C
0105            WRITE(1,515)
0106            WRITE(6,115)
0107        115 FORMAT(' ','COLUMNS')
0108        515 FORMAT(     'COLUMNS')
0109            DO 23 N=1,ISLAD
0110            IAA=NA(N)
0111            JJ=1
0112            IPP=IP(N,JJ)
0113            DO 23 IA=1,IAA
0114            CALL WATERD(POPUD,WD)
0115            CALL LAND(POPUD,RD)
0116            POPUD(55) = -1.0
0117            DO 23 ID=1,55
0118            DO 25 J=1,11,2
0119         25 WRITE(1,509) ISNAME(N),ANAME(IA),IDNAME(ID),
           $     ISNAME(N),ANAME(IA),RNAME(1),TINTER(J),WD(ID,J),
           $     ISNAME(N),ANAME(IA),RNAME(1),TINTER(J+1),WD(ID,J+1)
```

```
0120           DO 24 IR=2,NR
0121        24 WRITE(1,510) ISNAME(N),ANAME(IA),IDNAME(ID),ISNAME(N),
              $     ANAME(IA),RNAME(IR),RD(IR,ID)
0122           WRITE(1,519) ISNAME(N),ANAME(IA),IDNAME(ID),AMATRX(ID)
0123           DO 26 J=1,53,2
0124        26 WRITE(1,619) ISNAME(N),ANAME(IA),IDNAME(ID),IDNAME(J),
              $ A(J,ID),IDNAME(J+1),A(J+1,ID)
0125           WRITE(1,805) ISNAME(N),ANAME(IA),IDNAME(ID),
              $  ISNAME(N),ANAME(IA),POPUD(ID)
0126           IF(ID .GT. 54) POPUD(55) = 0.0
0127           WRITE(1,622) ISNAME(N),ANAME(IA),IDNAME(ID),POPUD(ID)
0128            POPUD(55) =-1.0
0129           IF(IA .GT. IPP) GO TO 1020
0130           GO TO 23
0131      1020 JJ=JJ+1
0132           IPP=IPP + IP(N,JJ)
0133        23 WRITE(1,1013) ISNAME(N),ANAME(IA),IDNAME(ID),ISNAME(N),JJ,
              $  POPUD(ID)
0134      1013 FORMAT(     4X,2A1,A2,6X,A1,'POPULG',I1,2X,F12.5)
0135       127 FORMAT(4X,2A1,A2,6X,2A1,'INDU',I2,F12.5)
0136       805 FORMAT(     4X,2A1,A2,6X,2A1,'POPUL',3X,F12.5)
0137       619 FORMAT(4X,2A1,A2,6X,'INDUS',A2,3X,F12.5,3X,'INDUS',A2,3X,F12.5)
0138       622 FORMAT(4X,2A1,A2,6X,'POPULAT',3X,F12.5)
0139       519 FORMAT(     4X,2A1,A2,6X,'ZVALUE',4X,F12.5)
0140       509 FORMAT(     4X,2A1,A2,6X,2A1,2A2,4X,F12.5,3X,2A1,2A2,4X,F12.5)
0141       510 FORMAT(     4X,2A1,A2,6X,2A1,A2,6X,F12.5)
         C
         C RHS SECTION
         C
0142           WRITE(1,540)
0143           WRITE(6,140)
0144       140 FORMAT(' ','RHS')
0145       540 FORMAT(     'RHS')
0146       541 FORMAT(     4X,'RHSSIDE',3X,2A1,2A2,4X,F12.3,3X,2A1,2A2,4X,F12.3)
0147       141 FORMAT(' ',4X,'RHSSIDE',3X,2A1,2A2,4X,F12.3,3X,2A1,2A2,4X,F12.3)
0148           DO 152 N=1,ISLAD
0149           IAA=NA(N)
0150           DO 152 IA=1,IAA
0151           DO 142 J=1,11,2
0152           WRITE(1,541) ISNAME(N),ANAME(IA),RNAME(1),TINTER(J),RWS(N,IA,J),
              $  ISNAME(N),ANAME(IA),RNAME(1),TINTER(J+1),RWS(N,IA,J+1)
0153       142 WRITE(6,141) ISNAME(N),ANAME(IA),RNAME(1),TINTER(J),RWS(N,IA,J),
              $  ISNAME(N),ANAME(IA),RNAME(1),TINTER(J+1),RWS(N,IA,J+1)
0154           DO 152 J=2,NR
0155           WRITE(1,553) ISNAME(N),ANAME(IA),RNAME(J),RS(N,IA,J)
0156       152 WRITE(6,153) ISNAME(N),ANAME(IA),RNAME(J),RS(N,IA,J)
0157           DO 702 K=1,54
0158           WRITE(6,703) IDNAME(K),FINALD(K)
0159       702 WRITE(1,704) IDNAME(K),FINALD(K)
0160       703 FORMAT(' ',4X,'RHSSIDE',3X,'INDUS',A2,3X,F12.2)
0161       704 FORMAT(     4X,'RHSSIDE',3X,'INDUS',A2,3X,F12.2)
0162       129 FORMAT(' ',4X,'RHSSIDE',3X,2A1,'INDU',I2,2X,'0.0')
0163       130 FORMAT(     4X,'RHSSIDE',3X,2A1,'INDU',I2,2X,'0.0')
0164           WRITE(6,554) EXPOPU
0165           WRITE(1,555) EXPOPU
0166           DO 1014 N=1,ISLAD
```

```
      NO=NPG(N)
      DO 1014 K=1,NO
      WRITE(6,1016) ISNAME(N),K
 1014 WRITE(1,1017) ISNAME(N),K
 1016 FORMAT(' ',4X,'RHSSIDE',3X,A1,'POPULG',I1,2X,'0.0')
 1017 FORMAT(    4X,'RHSSIDE',3X,A1,'POPULG',I1,2X,'0.0')
  554 FORMAT(' ',4X,'RHSSIDE',3X,'POPULAT',3X,F12.5)
  555 FORMAT(    4X,'RHSSIDE',3X,'POPULAT',3X,F12.5)
  153 FORMAT(' ',4X,'RHSSIDE',3X,2A1,A2,6X,F12.3,3X,2A1,A2,6X,F12.3)
  553 FORMAT(    4X,'RHSSIDE',3X,2A1,A2,6X,F12.3,3X,2A1,A2,6X,F12.3)
C
C RANGES SECTION ( RANGES NAME 'LODEMAND'
C
      WRITE(6,821)
      WRITE(1,830)
  821 FORMAT(' ','RANGES')
  830 FORMAT(    'RANGES')
      DO 825 J=1,54,2
      WRITE(1,822) IDNAME(J),RANG(J),IDNAME(J+1),RANG(J+1)
  825 WRITE(6,823) IDNAME(J),RANG(J),IDNAME(J+1),RANG(J+1)
  822 FORMAT(4X,'LODEMAND',2X,'INDUS',A2,3X,F12.2,3X,'INDUS',A2,3X,
     $ F12.2)
  823 FORMAT(' ',4X,'LODEMAND',2X,'INDUS',A2,3X,F12.2,3X,'INDUS',A2,3X
     $ F12.2)
      WRITE(1,840) EXPOPL
      WRITE(6,841) EXPOPL
  841 FORMAT(' ',4X,'LODEMAND',2X,'POPULAT',3X,F12.2)
  840 FORMAT(    4X,'LODEMAND',2X,'POPULAT',3X,F12.2)
C
C BOUND SECTION (BOUNC NAME= SIZE)
C
      WRITE(1,564)
      WRITE(6,565)
  564 FORMAT('BOUNDS')
  565 FORMAT(' ','BOUNDS')
  569 FORMAT(A2,A4,2A2)
      DIMENSION VALUE(56)
      INTEGER PP(56)
      DO 568 K=1,1000
      READ(5,569,END=701) TYPE,BNAME1,BNAME2,COLNAM
      READ(5,1004) NO
      READ(5,1004)  (PP(J),J=1,NO)
      READ(5,104)  (VALUE(K1),K1=1,NO)
      DO 568 I=1,NO
      L=PP(I)
      WRITE(1,566) TYPE,BNAME1,BNAME2,COLNAM,IDNAME(L),VALUE(I)
  568 WRITE(6,567) TYPE,BNAME1,BNAME2,COLNAM,IDNAME(L),VALUE(I)
 1004 FORMAT(40I2)
  566 FORMAT(    1X,A2,1X,A4,A2,4X,2A2,6X,F12.5)
  567 FORMAT(' ',1X,A2,1X,A4,A2,4X,2A2,6X,F12.5)
  701 WRITE(1,563)
      WRITE(6,163)
  163 FORMAT(' ','ENDATA')
  563 FORMAT(    'ENDATA')
      DIMENSION TEST(16)
      REWIND 1
```

```
          NOAREA =0
          DO 700 I=1,ISLAD
      700 NOAREA = NOAREA + NA(I)
          NOROWS = (NOAREA * 17) + 1
          NOROWS = NOROWS + 800
          DO 400 I=1,NOROWS
          READ(1,300) (TEST(K),K=1,16)
      400 WRITE(6,301) (TEST(K),K=1,16)
      300 FORMAT(15A4,A1)
          DO 3000 K=1,1600
     3000 READ(1,300) (TEST(I),I=1,16)
          DO 3001 I=1,250
          READ(1,300) (TEST(K),K=1,16)
     3001 WRITE(6,301) (TEST(K),K=1,16)
      301 FORMAT(' ',15A4,A1)
          REWIND 1
          END
```

```
      SUBROUTINE LAND(POPUD,RD)
      DIMENSION POPUD(55),RD(11,55),POLUT(4,6)
C  POLUT(J,I): POLLUTANT J IN LBS /ACRE-MONTH FROM ITH LAND(UL,PL ETC
C  EPRATI=EMPLOYED TO POPULATION, OURATI=OFFICE VERSUS RESIDENTIAL NE
      READ(5,10) ULCPA,PLCPA,TLCPA,SLD,ALD,HLD,EPRATI,OURATI
      DO 4 J=1,11
      DO 4 I=1,55
    4 RD(J,I) =0.0
      DO 6 J=1,4
    6 READ(5,10) (POLUT(J,I),I=1,6)
   10 FORMAT( 8F10.4)
      DO 1 I=1,54
    1 RD(2,I) = POPUD(I)*EPRATI*10.0*ULCPA*OURATI
      DO 2 I=1,54
    2 RD(3,I)=POPUD(I)*EPRATI*10.0*PLCPA*OURATI
      DO 3 I=1,54
    3 RD(4,I)=POPUD(I)*EPRATI*10.0*TLCPA
      RD(2,55) = ULCPA*10.0
      RD(3,55) = PLCPA*10.0
      RD(4,55) = TLCPA*10.0*(1.0-EPRATI)
      RD(5,1)=SLD
      RD(6,2)=ALD
       RD(7,5)=HLD
C WE ONLY CHECK THE CRITICAL MONTH
      DO 5 J=8,11
      DO 5 I=1,54
    5 RD(J,I) = 0.0
      DO 7 J=8,11
      DO 7 I=1,54
      DO 7 M=2,7
    7 RD(J,I) = RD(J,I) + RD(M,I)*POLUT(J-7,M-1)
      DO 100 K=2,11
  100 WRITE(6,11) (RD(K,I),I=1,54)
      DO 20 I=5,11
   20 RD(I,55) =0.0
   11 FORMAT(' ',10F13.5)
      RETURN
      END
```

```
      C   EVAPA-PERCENT OF ANNUAL EVAPORATION.
      C   VARIAT-WACPA*VARIAT(J) = PER CAPITA CONSUMPTION IN THE MONTH J.
      C          VARIAT IN DECIMAL OF WACPA.
      C   WACPA-MEAN WATER COMSUMPTION IN GALLONS PER PERSON PER DAY.
      C   WD(I)-DIRECT ANNUAL WATER CONSUMPTION OF INDUSTRY I IN 10*4 GALLONS P
      C       10*4 $ OUTPUT
            SUBROUTINE WATERD(POPUD,WCONSU)
        100 FORMAT(8F10.2)
            DIMENSION VARIAT(12),EVAPVA(12),WCONSU(55,12),WA(54),POPUD(56)
            DO 3 K=1,54
          3 WA(K)=0.0
            READ(5,100) EPRATI,DAYUSE
            READ(5,100) (EVAPVA(J),J=1,12)
            READ(5,100) (VARIAT(J),J=1,12)
            READ(5,100) WACPA, (WA(I),I=1,5),WA(22),WA(32)
            READ(5,100) WA(45)
            WRITE(6,101)WACPA, (WA(I),I=1,5),WA(22),WA(32),WA(45)
            DO 2 I=1,54
            DO 4 J=1,12
          4 WCONSU(I,J)=(POPUD(I)*WACPA*VARIAT(J)*30.0*DAYUSE)/1000.0
          2 WRITE(6,101) (WCONSU(I,J),J=1,12)
            WRITE(6,101) (WA(I),I=1,54)
            WRITE(6,101) (EVAPVA(J),J=1,12)
            DO 5 I=1,54
            DO 5 J=1,12
          5 WCONSU(I,J) = WCONSU(I,J) + (0.01*EVAPVA(J)*WA(I))
            DO 6 I=1,54
          6 WRITE(6,101) (WCONSU(I,J),J=1,12)
            DO 7 J=1,12
          7 WCONSU(55,J)=(WACPA*(1.0-DAYUSE)*VARIAT(J)*30.0)/1000.0
        101 FORMAT(' ',12F10.3)
            RETURN
            END
```

Appendix V. SOME INPUT DATA USED IN THE EXAMPLE

1) <u>Population supported by each industry, in 10 persons/10^4\$</u>

Industry No.	1	2	3	4	5	6	7	8
Population	0.1174	0.0282	0.1207	0.0945	0.1231	0.0202	0.0999	0.0229

Industry No.	9	10	11	12	13	14	15	16
Population	0.1133	0.0167	0.0724	0.1150	0.2174	0.1249	0.1377	0.3010

Industry No.	17	18	19	20	21	22	23	24
Population	0.7250	0.2109	0.0	0.22713	0.13147	0.0	0.0	0.6797

Industry No.	25	26	27	28	29	30	31	32
Population	0.0	0.2751	0.1307	0.0	0.0	0.0	0.1699	0.1097

Industry No.	33	34	35	36	37	38	39	40
Population	0.3250	0.3965	0.1247	0.3024	0.3233	0.1315	0.0623	0.2101

Industry No.	41	42	43	44	45	46	47	48
Population	0.3559	0.3416	0.1250	0.0222	0.1721	0.2409	0.3511	0.2160

Industry No.	49	50	51	52	53	54		
Population	0.4255	0.1115	0.7031	0.3753	0.1130	0.0		

2) Planning year = 30

3) Annual labor productivity growth rate

Industry No.	1	2	3	4	5	6	7	8
Rate	0.025	0.0250	0.0325	0.0415	0.0427	0.0544	0.0611	0.0537

Industry No.	9	10	11	12	13	14	15	16
Rate	0.030	0.0171	0.0303	0.0303	0.0196	0.0483	0.0463	0.0504

Industry No.	17	18	19	20	21	22	23	24
Rate	0.0303	0.0303	0.0359	0.0303	0.0303	0.0531	0.0309	0.0457

Industry No.	25	26	27	28	29	30	31	32
Rate	0.0219	0.0303	0.0303	0.0555	0.0303	0.0303	0.0303	0.0171

Industry No.	33	34	35	36	37	38	39	40
Rate	0.0171	0.0171	0.0171	0.0773	0.0171	0.0171	0.0590	0.0171

Industry No.	41	42	43	44	45	46	47	48
Rate	0.0171	0.0171	0.0171	0.0171	0.0171	0.0171	0.0171	0.0171

Industry No.	49	50	51	52	53	54		
Rate	0.0171	0.0171	0.0171	0.0171	0.0171	0.0171		

3) Projected population for Kauai year 2000 = 61,000.0 persons

Kauai 1970 population = 29,520.0

4) Economic projections in $10^4$$ for year 2000 versus 1970 economic final demand

Year \ Thrust	1	2	3	4	5	6	7	8
2000	0.0	59.91	357.10	4117.75	457.69	57.81	401.3	17.0
1970	0.0	41.00	357.00	4054.00	85.00	10.00	63.00	3.0

Year \ Thrust	9	10	11	12	13	14	15	16
2000	32.33	99.35	194.64	233.73	243.15	483.00	512.38	200.07
1970	7.00	28.00	53.00	77.00	75.00	84.00	132.00	30.00

Year \ Thrust	17	18	19	20	21	22	23	24
2000	24.54	--	--	367.48	1022.9	--	--	--
1970	5.0	--	--	74.0	84.0	--	--	--

Year \ Thrust	25	26	27	28	29	30	31	32
2000	--	352.96	--	--	--	--	--	3664.82
1970	--	84.0	--	--	--	--	--	1013.00

Year \ Thrust	33	34	35	36	37	38	39	40
2000	282.57	38.57	362.40	712.9	904.72	1149.73	1689.9	994.14
1970	63.0	5.0	54.0	42.0	162.0	187.0	173.0	205.0

Year \ Thrust	41	42	43	44	45	46	47	48
2000	5583.62	1571.00	838.79	567.84	21513.0	692.0	3101.36	1356.36
1970	1310.0	373.0	179.0	108.0	1959.0	146.0	557.0	303.0

Year \ Thrust	49	50	51	52	53	54
2000	594.4	3085.33	449.66	246.47	870.24	573.9
1970	135.0	496.0	188.0	38.0	119.0	83.0

5) Employment/population ratio = 0.459

Office use of water, in fraction of average per capita water consumption = 0.2128

6) Monthly evaporation in percent of annual total evaporation (Kauai Hydrographic Area I)

Month	1	2	3	4	5	6	7	8	9	10	11	12
Evaporation	7.02	7.50	8.47	8.48	9.31	9.20	9.72	9.19	8.78	7.93	7.15	6.71

7) Monthly variation of per capita water consumption, in fraction of average per capita water consumption

Month	1	2	3	4	5	6	7	8	9	10	11	12
Variation	0.72	0.69	0.83	0.94	1.19	1.25	1.20	1.43	1.29	1.07	0.96	0.79

8) Average per capita water consumption in gallons per day and industry annual indirect water consumption, in gallons/$(1970) output (Hydrographic Area II, Kauai)

Average per capita water consumption for year 2000, Kauai - 223.0

Industry No.	1	2	3	4	5	22	32	45
Water Consumption	2201.45	25.0	26.0	400.0	57.0	10.6	0.15	20.0

9) Per capita land requirement, in acres and industry land requirement, in acres/10^4 \$ (Kauai Area II)

Urban land : 0.2274 acres/person

Park land : 0.0040 acres/person

Total land : 5.5925 acres/person

Sugarcane land : 20.465 acres/10^4 \$ output

Pineapple land : 18.125 acres/10^4 \$ output
(vegetables, etc.)

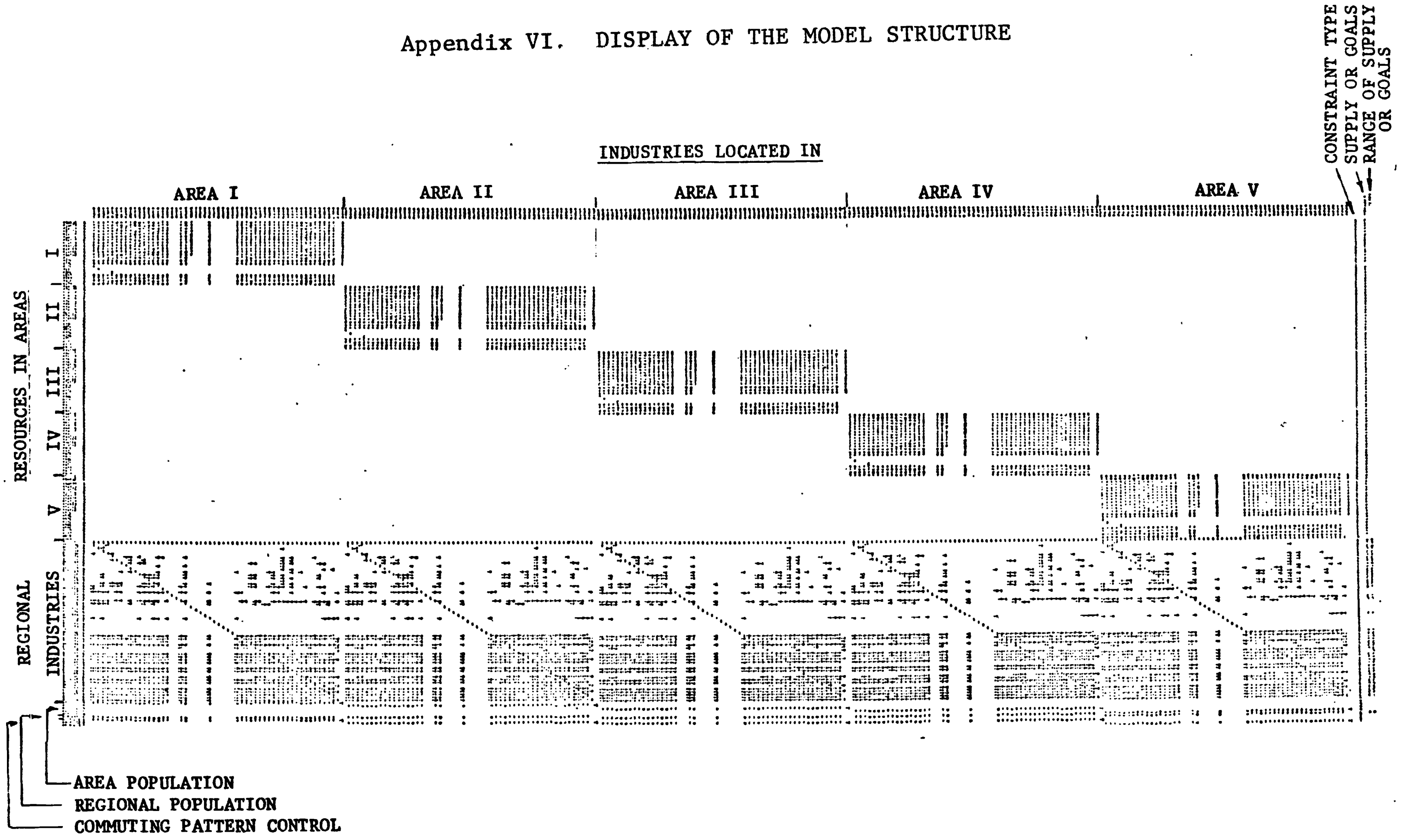
Pasture land : 393.673 acres/10^4 \$ output

Office density = residential density/0.2

10) Sediment, BOD, nitrogen and phosphor discharged from various land use, in tons/acre-year (Hydrographic Area II, Kauai)

Land Use	Urban	Park	Forest	Sugarcane	Pineapple	Pasture
Sediment	0.09	0.3	0.1	4.5	4.2	1.6
BOD	0.00567	0.0045	0.0045	0.0045	0.0045	0.0045
Nitrogen	0.0000115	0.00205	0.00205	0.00205	0.00205	0.00205
Phosphor	0.000174	0.000134	0.000134	0.000134	0.000134	0.000134

Appendix VI. DISPLAY OF THE MODEL STRUCTURE



Appendix VII. LISTING OF 54 BASIC INDUSTRIES

SUGAR CANE AND OTHER FIELD CROPS
PINEAPPLE, FRUITS, NUTS, AND VEGETABLES
CANNED FRUITS, VEGETABLES, AND SEA FOODS
4 SUGAR PROCESSING
5 BEEF & HOGS
6 DAIRY FARM PRODUCTS
7 POULTRY
8 COMMERCIAL FISHING
9 OTHER AGRICULTURAL PRODUCTS
10 MINING
11 MEAT PRODUCTS
12 MILK PRODUCTS
13 BAKERY PRODUCTS
14 BEVERAGES
15 OTHER FOOD PRODUCTS
16 TEXTILES & APPAREL
17 LUMBER & WOOD PRODUCTS, EXCEPT FURNITURE
18 FURNITURE & FIXTURES
19 PAPER & PAPER PRODUCTS
20 PRINTING & PUBLISHING
21 CHEMICALS & ALLIED PRODUCTS
22 PETROLEUM REFINING
23 RUBBER, MISC. PLASTIC & LEATHER PRODUCTS
24 CEMENT, STONE & CLAY PRODUCTS
25 PRIMARY METALS
26 FABRICATED METAL PRODUCTS
27 MACHINERY, EXCEPT ELECTRICAL
28 ELECTRICAL MACHINERY, EQUIPMENT & SUPPLY
29 TRANSPORT EQUIPMENT
30 INSTRUMENTS
31 MISCELLANEOUS MANUFACTURING
32 CONSTRUCTION
33 TRUCKING AND WAREHOUSING
34 TRANSPORTATION SERVICES
35 OCEAN TRANSPORTATION
36 AIR TRANSPORTATION
37 LOCAL GROUND TRANSPORTATION
38 COMMUNICATION
39 ELECTRICITY, GAS & SANITARY SERVICES
40 WHOLESALE TRADE
41 RETAIL TRADE
42 EATING & DRINKING PLACES * — * VISITOR INDUSTRY
43 BANKING & FINANCE
44 REAL ESTATE
45 HOTELS *
46 PERSONAL SERVICES
47 BUSINESS SERVICES
48 AUTO & MISCELLANEOUS REPAIR
49 AMUSEMENT SERVICES *
50 HEALTH & PROFESSIONAL SERVICES
51 EDUCATION & OTHER SERVICES
52 FEDERAL GOVERNMENT ENTERPRISES
53 STATE & LOCAL GOVERNMENT ENTERPRISES
54 DUMMY INDUSTRIES
TOTAL LOCAL PURCHASES